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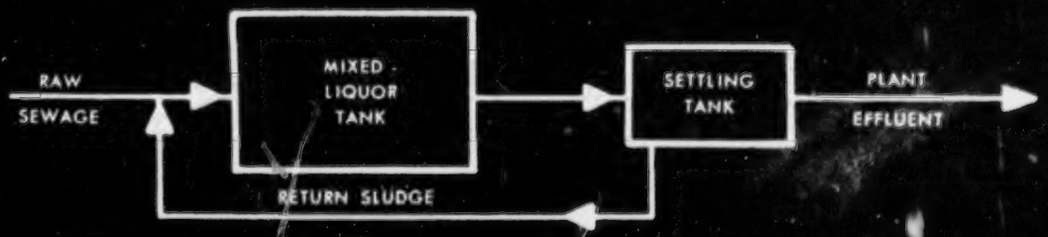
EXTENDED-AERATION PLANTS *and* INTERMITTENT WATERCOURSES



U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service

EXTENDED-AERATION PLANTS AND INTERMITTENT WATERCOURSES

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U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
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ABSTRACT

Two basic extended-aeration plants that discharge effluents to intermittent watercourses were studied during various seasons of the year. Except for periods of slug discharges, the plants produced effluents with a BOD of less than 35 mg/1 and suspended solids less than 30 mg/1. Plant efficiency was directly related to the amount of solids lost as a result of fluctuations in raw waste flow or as a result of denitrification and rising of solids in the sedimentation basin and consequent overflow. With the addition of sludge-wasting facilities or effluent-polishing units, these plants would be capable of efficient continuous operation for long periods.

Periodic heavy discharges of suspended solids formed sludge deposits in the two streams receiving effluent from the plants. Counts of benthic forms above and below the plant outfalls and at sampling points downstream clearly showed the effect of these deposits. Algal growths were profuse in unshaded portions of the streams, indicating high nutrient levels.

EXTENDED-AERATION PLANTS AND INTERMITTENT WATERCOURSES

SUMMARY

Use of extended-aeration plants has expanded rapidly, from 3 plants in 1950 to over 1,200 in 1960, and over 2,600 in 1962. The rapidly increasing number of installations has intensified concern of regulatory agencies and others about the quality of the effluent produced by these plants and its effect on small watercourses.

Accumulation of solids within the system is an inherent characteristic of an extended-aeration plant, and the efficiency of a plant's performance is directly related to the amount of solids lost in the effluent. The principle causes of excessive solids loss are extreme fluctuations in raw waste flow, floating solids losses due to denitrification in the sedimentation basin, and lack of routine solids wasting and disposal.

The degree of nitrification carried out in a plant has a very significant effect on effluent quality. The nitrogenous oxygen demand of the effluent must be considered when the oxygen demand of the effluent is compared with the predominantly carbonaceous demand of the influent.

Two basic extended-aeration plants (solids control not practiced) that discharge effluent to intermittent watercourses were studied during warm- and cold-weather conditions. Exclusive of periods of slug discharges of solids, the two plants produced effluents having a biochemical oxygen demand of less than 35 milligrams per liter and suspended solids of less than 30 milligrams per liter, with frequent periods when both concentrations were 20 milligrams per liter or less. Without solids control, excess solids built up and were swept out of the plant with each significant fluctuation in flow rate.

Biological investigations of the streams indicated the potential for the development of aquatic nuisances caused by periodic heavy discharges of suspended solids in the plant effluent. Sludge deposits occurred, and nutrient levels were high, as reflected by biological activity in the streams.

Various methods for control of solids are discussed, including mixed-liquor suspended-solids control and effluent-polishing techniques.

INTRODUCTION

The increase in the number of extended-aeration plants used in the United States is impressive, from 3 in 1950, to 1,224 in 1960, and to more than 2,600 in 1962. A preliminary evaluation of these plants has been made by Porges and Morris.[1]

Extended-aeration sewage treatment is a modification of the activated-sludge process. The basic plant is designed to provide detention in an aeration tank for 18 to 24 hours, detention in a final settling tank for 3 to 6 hours, and 100 percent return of settleable solids to the aeration tank. Many modifications of this basic concept have been developed in an effort to provide better control of the process.

The statement has often been made that the extended-aeration process is capable of producing a high-quality effluent if plants are properly designed and operated.[2, 3, 4] When separate sludge wasting is not practiced, a clear effluent with a low biochemical oxygen demand (BOD) can be produced until the mixed-liquor suspended solids build up to equilibrium, after which solids are discharged in the effluent, lowering the effluent quality.[5]

Early studies reported lack of data on the fate of the aerobically digested sludge discharged in the plant effluent and the effect of the solids in the sludge on the receiving stream.[1]

Recent reports indicate that it is impossible to operate an extended-aeration system without sludge accumulation.[5, 6, 7, 8] Washington and Symons[7] investigated the nature of the accumulated volatile solids over a long period of time. It was reported that these solids, which are mainly polysaccharide in nature but also contain fatty acids and organic nitrogen, accumulate because they are biologically inert to the organisms in activated sludge and that they therefore could be considered inactive mass.

Because most of the solids lost in plant effluent consist of this biologically inert organic matter, the effluent BOD is not as high as would be expected with comparable solids losses from a conventional activated-sludge plant.[8] The BOD of the active portion of the solids lost constitutes nearly all of the carbonaceous effluent BOD, however.[4, 8]

The need for controlling loss of solids to maintain an effluent of high quality has been recognized by many investigators.[2, 3, 5, 9] It has also been noted that incomplete nitrification in an extended-aeration plant can cause a substantial increase in the effluent BOD, over and beyond that exerted by the solids and the very small demand exerted by unassimilated organics. Generally, control of solids discharged in the effluent has been considered the primary factor affecting extended-aeration plant efficiency.

Because many small plants have been built without provisions for separate sludge wasting, state agencies have been concerned about the effects on receiving watercourses of solids discharged from these plants. To determine these effects on intermittent streams, periodic field studies were carried out from August 1961 to May 1962 at two basic extended-aeration plants where solids were not controlled but allowed to escape in the effluent.

The objectives of this study were (1) to evaluate plant efficiency and solids handling problems, (2) to evaluate the effect of plant effluent on an intermittent watercourse when solids control is not practiced, and (3) to study these systems under various climatic conditions.

METHOD OF STUDY

Two basic extended-aeration plants that discharge effluent to separate intermittent watercourses were selected for study. Sampling stations were then selected to reflect a reliable picture of plant operations and of the effect of the effluent on stream conditions. Physical, chemical, bacteriological, and biological parameters were measured.

The two plants and streams were sampled every 2 hours for 1 week during different seasons of the year. Plant A and Stream A were sampled during August 1961 and March and May of 1962. Plant B and Stream B were sampled during August and December 1961 and March and May 1962.

Plant samples were taken at 2-hour intervals during each 24-hour period for 1 week. Stream samples were taken every 2 hours for 6 days during the 8-hour day shift and throughout one 24-hour period to determine diurnal fluctuations in dissolved oxygen (DO). The field samples were iced as collected and transported at the end of each shift to the Robert A. Taft Sanitary Engineering Center where laboratory personnel made daily composites. Biological samples for qualitative study were taken over a 2-day period during each weekly sampling run.

The 1960 edition of "Standard Methods for the Examination of Water and Wastewater" was used as a guide for all laboratory testing procedures. Temperature, DO, and pH were determined in the field. All other analytical and identification work was performed in the Sanitary Engineering Center laboratories.

Normal routine operating procedures were used at the two plants, both of which were operated by the same personnel. Operators attended each plant about 2 hours each weekday.

PRESENTATION OF DATA

The areas served by each plant under study are residential, Figure 1; the value of houses ranges from $10,000 to $18,000 in Area A and from $10,000 to $14,000 in Area B.

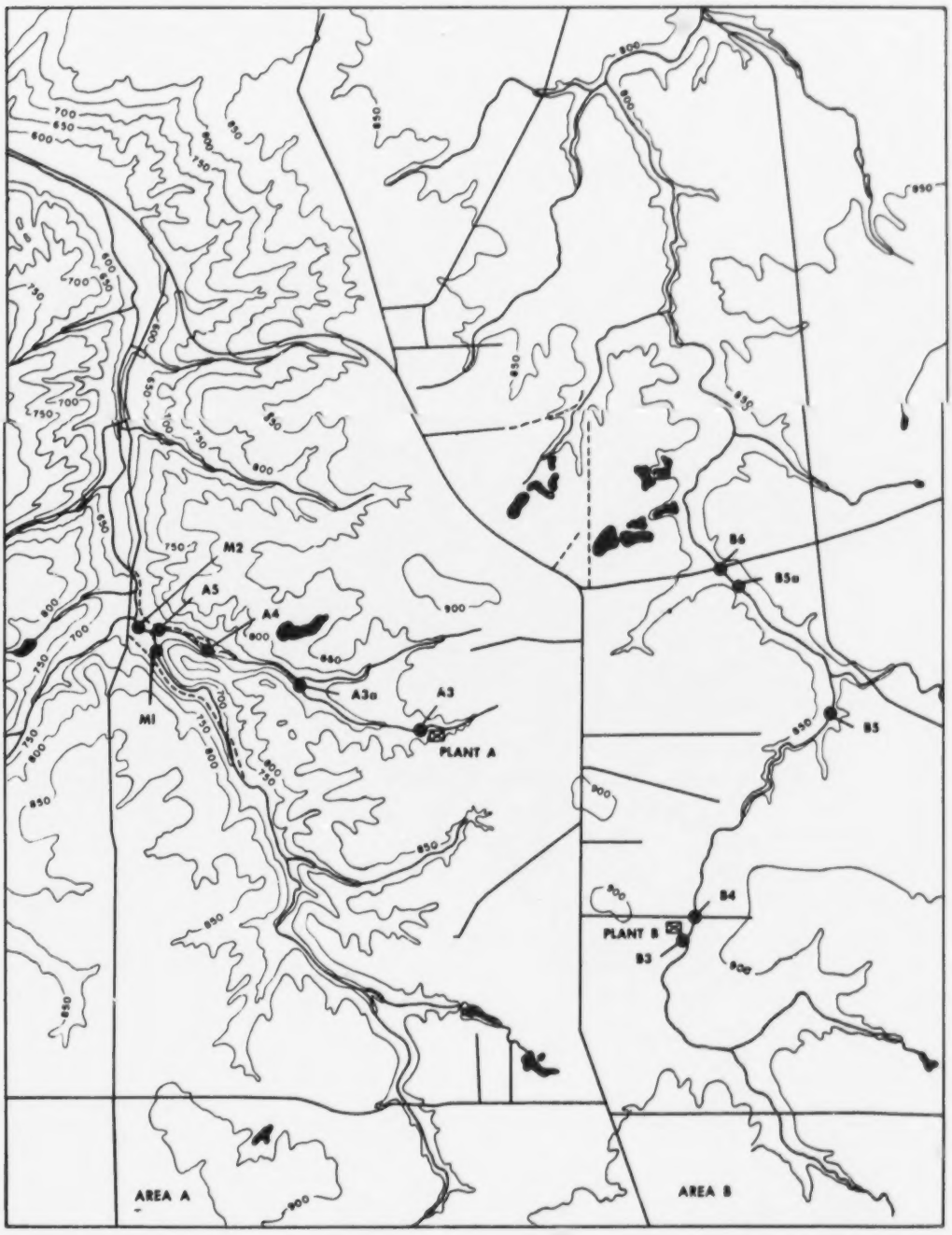


Figure 1. Locations of plants, sampling stations, and streams.

Plant A serves 752 persons and Plant B 488, based on 4.0 residents per house. Typical occupants are young couples with small children.

The topography of these areas is rolling, and surface drainage is good. The elevation differential is 200 feet in Area A and 70 feet in Area B. Stream A drops 170 feet in the 3,550-foot reach between station A3, just below Plant A, and station A5, just above the confluence of Stream A and the mainstream, Stream M. Stream B drops 35 feet in the 6,450-foot reach between B3 and B5a.

Sewage reaching the treatment plants is fresh, with dissolved oxygen frequently present, and contains no industrial or commercial wastes. Data indicate 0.32 pound BOD in 135 gallons of waste per capita per day in Area A in wet weather and 0.10 pound BOD in 29 gallons of waste per capita in dry weather. The corresponding values for Area B are 0.15 pound BOD in 75 gallons of waste per capita per day in wet weather and 0.12 pound BOD in 45 gallons of waste in dry weather.

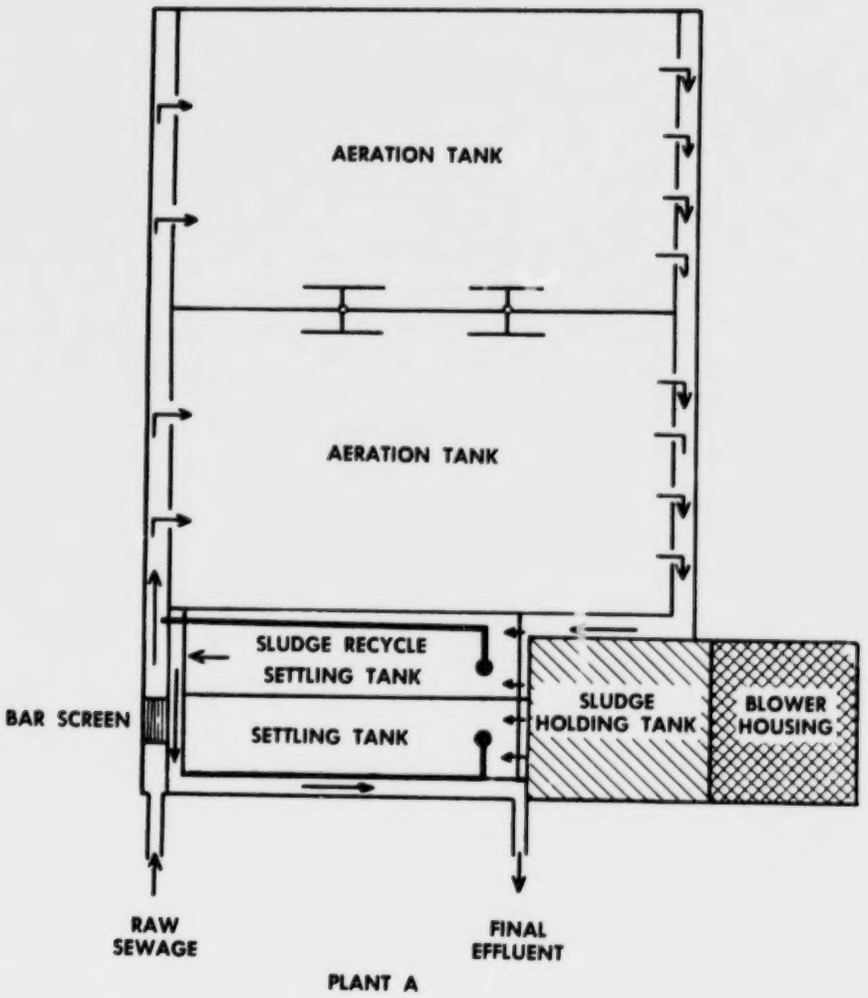
Concentration of raw sewage BOD is above the usual design value, 0.17 pound BOD in 100 gallons of waste per capita per day. A partial explanation of the higher organic concentration may be the cost of water, which averages $7.60 per month per house in the areas studies.

The two sewage treatment plants serving these areas are extended-aeration plants equipped with diffused-air systems. Plant A (Figure 2) is provided with a bar screen, two aeration tanks, two settling tanks, one sludge holding tank, three air pumps, two airlift sludge return pumps, and chlorination equipment. The total weir length in each sedimentation basin is 41.7 feet. Plant B (Figure 2) is equipped with a bar screen, one aeration tank, one settling tank, one sludge holding tank, two air pumps, one airlift sludge return pump, and a chlorine contact chamber.

Plant design data are compared with typical operation data for Plants A and B in Table 1. Actual flows are generally lower than design flows; thus, tank detention times are greater than design values.

Sludge holding tanks at both plants are operated as waste sludge tanks with all the accumulated sludge intermittently recycled into the aeration tank and discharged in the plant effluent.

Summaries of the analytical data from field samples and laboratory analyses are presented in Tables 2 and 3. Daily analytical data are given in Appendixes A and B.



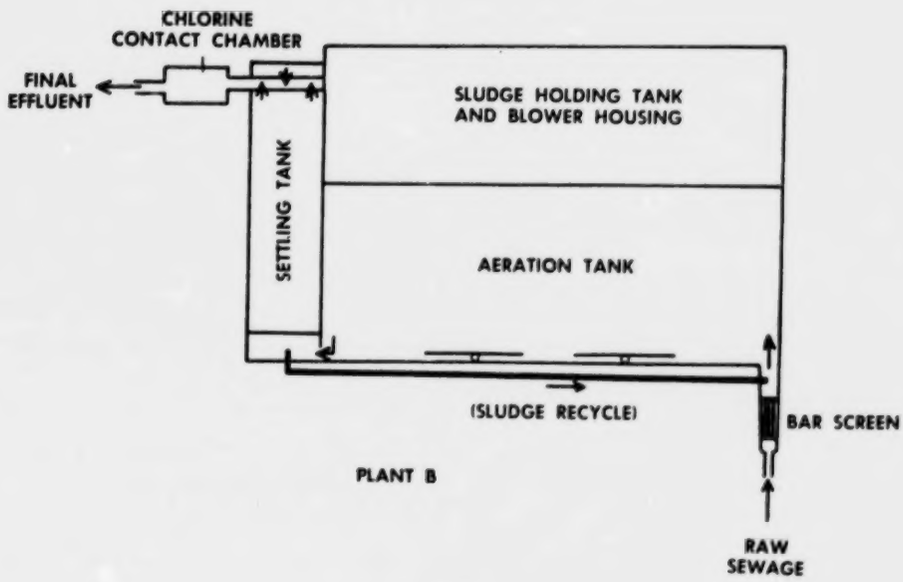


Figure 2. Plans of plants.

TABLE 1. DESIGN VALUES[a] COMPARED WITH TYPICAL OPERATION VALUES FOR PLANTS A AND B.

	Population	Flow, gpd	Aeration tank			Settling tank[b]			Sludge recirculation ratio
			BOD, lb	BOD, lb/1000 ft^3	Air supplied, ft^3/lb BOD	Retention, hr	Surface loading rate, gpd/ft^2	Weir overflow rates, gpd/ft	
Plant A									
Design	1,200	125,000	200	16	2,100	4.2	400	1,500	1 to 1
Typical operation	752	70,000	175	14	2,100	7.6	220	840	1.8 to 1
Plant B									
Design	600	60,000	100	16.7	2,100	3.9	415	2,760	1 to 1
Typical operation	482	25,000	65	10.8	4,300	9.4	173	1,150	2.4 to 1

[a]Design based on flow of 100 gpd per person and 0.167 pound BOD per person per day and 24 hours of aeration.
[b]Excluding recirculation.

PLANT A

Plant A flows varied widely, from one-sixth of the design value in August to twice the design value in March. The December 1961 field study was discontinued because of excessively high flow and loss of mixed-liquor solids. Open trenches for an unfinished sewer extension and heavy rainfall caused this excessive combined flow

The low volatile fraction of suspended solids in the raw sewage during wet weather reflected a substantial amount of inorganic material contributed by storm water infiltration.

Periods of poor plant performance with loss of solids in the effluent generally corresponded to periods of high hydraulic load. Concentrations of suspended solids in the effluent occasionally exceeded the suspended solids in the raw sewage; however, the volatile suspended-solids concentration in the effluent was always less than the corresponding value in the raw sewage. Suspended-solids reduction varied from no reduction to a maximum of 98 percent, based on daily composite samples.

The BOD in raw-sewage samples composited daily varied from 82 to 550 milligrams per liter and the plant effluent BOD varied from 8 to 500 milligrams per liter. BOD reduction effiency varied from no reduction to a maximum of 97 percent. The efficiency was above 75 percent for 17 days of the 20 days sampled, above 85 percent for 13 days, and above 90 percent for 8 days. During periods of normal flow, the effluent quality was good.

Correlation of seasonal temperature variations with plant performance was not possible because of storm-water infiltration in March and insufficient aeration in August.

TABLE 2 SUMMARY OF ANALYTICAL DATA FOR PLANT A AND STREAMS A AND M

	Plant A			Stream A			Stream M	
	Raw sewage	Mixed liquor	Effluent	Station A3	Station A4	Station A5	Station M1	Station M2[c]
Flow, gpd								
Aug. - Max.	25,300							
Min.	19,400							
Avg	21,900							
Mar. - Max.	247,800							
Min.	61,400							
Avg	103,500							
May - Max.	186,700							
Min.	47,600							
Avg	98,000							
pH[a]								
Aug. - [b] Max.	7.6	7.7	7.8	7.6	7.9	8.0		8.1
Min.	7.1		7.6	7.7	7.8	7.9		
Mar. - Max.	8.6	7.8	8.0	8.5	8.5	8.3	8.9	8.9
Min.	7.1	6.7	6.7	6.3	7.7	7.5	8.1	8.0
May - Max.	8.2	7.7	8.1	8.6	10.2	8.5	9.5	8.4
Min.	7.2	6.8	7.2	7.1	7.3	7.6	7.9	8.0
Temp. °C								
Aug. - Avg	22.9	23.6	23.2	21.5	21.2	20.6		23.5
Mar. - Avg	12.1	11.0	10.9	7.3	6.0	6.4	5.6	5.7
May - Avg	17.5	20.3	20.4	19.0	19.4	19.3	20.5	20.5
DO[a], **mg/l**								
Aug. - Max.		1.7	2.5	7.2	6.5	8.4		12.6
Min.		0.0	0.0	3.2	3.4	3.4		3.6
Avg		0.7	0.5	4.4	4.9	6.9		8.5
Mar. - Max.		5.7	4.6	14.1	13.5	13.0	14.6	14.5
Min.		0.0	0.0	6.0	10.1	9.9	10.5	10.4
Avg		2.2	1.2	11.2	11.9	11.9	13.0	12.6
May - Max.		2.3	1.8	8.0	9.5	9.3	11.4	12.3
Min.		0.3	0.0	4.9	6.2	6.0	2.2	2.5
Avg		0.8	0.7	6.4	8.0	8.3	8.6	9.0
BOD, mg/l								
Aug. - Max.	550		74	33	25	13		
Min.	330		55	28	12	3		
Avg	410		68	31	19	6		
Mar. - Max.	390		120	8	5	4	7	3
Min.	82		15	4	2	2	1	1
Avg	310		33	6	3	3	3	2
May - Max.	360		500	18	4	4	3	3
Min.	110		8	5	3	2	2	3
Avg	240		140	9	3	3	3	3
Suspended solids, mg/l								
Aug. - Max.	560	8,470	110	65	75	110		
Min.	270	7,170	75	16	32	13		
Avg	400	7,890	91	40	59	46		12
Mar. - Max.	760	3,760	530	55	29	72		
Min.	120	2,680	4	2	2	5		
Avg	330	3,120	110	16	12	22		
May - Max.	670	6,520	1,600	73	55	100		
Min.	88	5,240	5	23	34	18		
Avg	380	6,060	410	42	46	53		
NH_3, mg/l								
Aug. - Avg			37.4	31.50	10.9	2.90		0.40
Mar. - Avg			1.13	0.70	0.25	0.13		
May - Avg			4.07	0.72	0.25	0.15		
NO_2, mg/l								
Aug. - Avg			0.010	0.530	1.300	0.573		0.144
Mar. - Avg			0.548	0.174	0.052	0.029		
May - Avg			0.029	0.186	0.031	0.022		
NO_3, mg/l								
Aug. - Avg			0.01	0.86	6.03	4.65		0.150
Mar. - Avg			22.90	14.8	2.72	2.37		
May - Avg			0.39	1.98	1.25	1.12		
PO_4, mg/l								
Aug. - Avg			57	38	27	17		6
Mar. - Avg			39	17	8	6		
May - Avg			53	31	21	14		
ABS, mg/l								
Aug. - Avg			7.9	7.3	12.6	4.9		2.1
Mar. - Avg	10.2		5.2	3.0	1.5	1.3	0.2	0.5
May - Avg			7.2	5.9	3.4	2.1	0.6	1.2
***E. coli*, 1000's per 100 ml**								
Aug. - Avg	77,300		16,700			64.8		51.4
Mar. - Avg	21,900		1,923	70.4		12.8		
May - Avg	30,800		1,407	66.1		17.5		

NOTES: Maximum and minimum values are daily values for 24-hour composite samples.
Averages are for all 24-hour composites for the sampling period.

[a] DO and pH values are maximum and minimum of 2-hour samples for the sampling period.

[b] pH on 24-hour composites for August.

[c] Station M2 sampled in August for one day.

TABLE 3. SUMMARY OF ANALYTICAL DATA FOR PLANT B AND STREAM B

	Plant B			Stream B			
	Raw sewage	Mixed liquor	Effluent	Station 4	Station 5	Station 5a	Station 6[a]
Flow, gpd							
Aug. - Max.	26,000						
Min.	18,000						
Avg	20,900						
Dec. - Max.	47,300						
Min.	22,300						
Avg	32,000						
Mar. - Max.	71,500						
Min.	32,000						
Avg	50,400						
May - Max.	28,000						
Min.	21,300						
Avg	23,400						
pH							
Aug.[b] - Max.	7.7	7.4	7.7	8.0	8.1		8.4
Min.	7.3	7.3	7.4	7.5	7.8		7.9
Dec. - Max.	8.3	8.0	8.0	8.4	8.4	8.4	
Min.	7.1	6.8	6.9	7.3	7.3	7.4	
Mar. - Max.	8.3	8.4	7.8	9.5	8.5	8.5	
Min.	6.1	6.0	6.0	6.2	7.3	6.4	
May - Max.	8.3	7.6	7.8	8.1	8.3	8.5	
Min.	6.9	6.1	6.9	7.0	7.0	7.1	
Temp, °C							
Aug. - Avg	24.7	25.2	25.0	24.5	21.5		24.5
Dec. - Avg	14.9	12.8	12.1	3.8	2.6	3.1	
Mar. - Avg	11.2	10.4	10.3	4.9	4.4	4.2	
May - Avg	19.1	21.7	21.9	25.0	21.7	24.0	
DO, mg/l							
Aug. - Max.		4.0	4.6	7.7	12.7		31.7
Min.		0.0	0.8	2.2	2.5		2.1
Avg		1.8	1.6	5.0	6.9		9.5
Dec. - Max.		6.6	4.1	12.7	14.4	13.6	
Min.		0.3	0.0	7.9	8.3	9.4	
Avg		3.4	1.0	11.2	12.4	11.5	
Mar. - Max.		5.0	4.9	12.7	13.6	14.2	
Min.		0.0	0.0	7.7	10.0	8.6	
Avg		2.0	1.0	11.5	12.2	12.0	
May - Max.		0.9	2.4	13.4	6.5	14.5	
Min.		0.0	0.0	1.4	1.3	0.4	
Avg		0.4	0.3	8.0	3.6	7.7	
BOD, mg/l							
Aug. - Max.	360		11	8	6		8
Min.	280		6	3	4		4
Avg	320		9	5	5		6
Dec. - Max.	310		34	11	8	6	
Min.	170		8	4	3	4	
Avg	240		18	7	5	4	
Mar. - Max.	380		210	18	5	3	
Min.	140		21	3	3	2	
Avg	250		70	7	4	2	
May - Max.	380		34	9	6	13	
Min.	280		18	6	3	4	
Avg	310		26	8	4	6	
Suspended solids, mg/l							
Aug. - Max.	610	6,560	30	31	63		120
Min.	160	5,480	12	5	13		7
Avg	300	6,080	18	14	33		40
Dec. - Max.	520	7,240	1,500	100	56	310	
Min.	130	6,220	14	14	12	10	
Avg	270	6,540	250	42	34	68	
Mar. - Max.	170	5,380	690	83	92	210	
Min.	87	4,440	29	12	10	25	
Avg	120	5,070	130	47	48	91	
May - Max.	390	8,320	25	30	51	39	
Min.	180	7,860	12	12	15	13	
Avg	260	8,030	17	21	25	19	
NH_3, mg/l							
Aug. - Avg			0.48	0.63	0.29		0.37
Dec. - Avg			0.94	0.50	0.52	0.63	
Mar. - Avg			1.79	0.35	0.39	0.40	
May - Avg			4.87	3.33	0.62	1.22	
NO_2, mg/l							
Aug. - Avg			0.192	0.168	0.084		0.191
Dec. - Avg			0.287	0.081	0.028	0.029	
Mar. - Avg			0.265	0.023	0.019	0.017	
May - Avg			0.008	0.337	0.086	0.266	
NO_3, mg/l							
Aug. - Avg			27.50	23.50	9.56		1.47
Dec. - Avg			20.20	4.00	3.10	3.30	
Mar. - Avg			17.50	1.40	1.03	1.06	
May - Avg			0.18	0.36	0.55	0.91	
PO_4, mg/l							
Aug. - Avg			71	64	16		9
Dec. - Avg			80	11	8	7	
Mar. - Avg			38	3	2	2	
May - Avg			61	39	10	11	
ABS, mg/l							
Aug. - Avg			1.2	1.0	0.8		1.0
Dec. - Avg							
Mar. - Avg	9.5		5.8	1.0	0.3	0.3	
May - Avg	26.7		7.2	5.7	2.7	2.7	
E. coli, 1000's per 100 ml							
Aug. - Avg	52,700		797		72		
Dec. - Avg	26,500		441		27		
Mar. - Avg	21,500		2,442	92	98		
May - Avg	36,300		3,850	102	8		

NOTES: Maximum and minimum are daily values for 24-hour composite samples. Averages are for all 24-hour composites for the sampling period.

[a] DO and pH values are maximum and minimum of 2-hour samples for the sampling period.

[b] pH on 24-hour composites for August.

Significant nitrification in the plant occurred only during the March study. The reduction of the nitrogenous oxygen demand of the effluent during March is one factor that accounted for higher DO in the stream. When only a small degree of nitrification was obtained in the plant, some occurred in the stream, as shown by the increasing nitrate values at downstream stations.

The average coliform reduction was 78 percent for August and 95 percent for March and May with a maximum of 99.7 percent on March 18. On March 21 the effluent coliform count exceeded the raw-sewage count because storm water diluted the raw sewage and the increased flow carried solids into the effluent. Coliform counts decreased at successive downstream stations. At station A5, maximum and minimum values were 126,000 and 2,700 per 100 milliliters; the average was 31,700 per 100 milliliters for the three test periods (Appendix A). Chlorination of plant effluent was discontinued during the study periods.

Electric power costs (Table 4) ranged from about 1 to 1-1/2 cents per 1,000 cubic feet of air used for all purposes. Separate measurements of air for aeration and for sludge pumping were not attempted.

TABLE 4. ELECTRIC POWER COST DATA FOR PLANTS A AND B

	Flow, gpd	Air, ft^3/day	kwh/day	$/kwh	$/day	$/1000 ft^3 air	$/mg water	Notes
Plant A								
Aug.	21,900	204,500	130	0.0232	3.02	0.0147	138.00	One-half of plant in service
Mar.	103,480	408,100	259	0.0175	4.52	0.0111	44.00	Includes storm flow
May	97,990	313,260	218	0.0189	4.11	0.0131	42.00	Includes storm flow
Plant B								
Aug.	20,900	358,500	220	0.0204	4.50	0.0126	215.00	
Dec.	32,030	329,700	230	0.0209	4.81	0.0146	150.00	
Mar.	50,380	213,000	202	0.0185	3.73	0.0174	74.00	Includes storm flow.
May	23,360	200,500	168	0.0188	3.16	0.0158	135.00	

STREAM A

The purposes of the biological studies were to determine possible degradation effects of plant effluent upon aquatic life in the stream and to determine whether nutrients and sludge deposits were creating an environment in which aquatic nuisances might flourish.

A qualitative study of bottom fauna and fish populations was conducted. Benthic organisms were collected with a Surber square foot sampler and a Bueno Ventura hand dip net. Fish were collected in a minnow seine with a 1/4-inch mesh and an over all dimen-

sion of 4 by 6 feet. Efforts to collect bottom organisms at each station were continued until no additional forms were found, and then for an additional 1/2 hour.

Identification of organisms was usually carried to the family, and occasionally to genera or species. For graphic presentation, organisms were separated into two groups, those intolerant of organic pollution (clean-water forms) and those tolerant of organic pollution (Figure 3). Examples of clean-water forms are immature stages of mayflies, alder flies, stoneflies, and fish. Tolerant forms are sludgeworms, bloodworms, and aquatic sow bugs. A summary of all groups found in Stream A is given in Appendix C.

Stream A is 2 to 6 feet in width, with steep banks on three-quarters of the reach studied, and has a gradient of approximately 250 feet per mile. The stream bed is characterized by many falls, riffles, and short pools, none exceeding 2 feet in depth. Sludge beds were observed downstream from the plant outfall for a distance of approximately 2,000 feet; some of these beds were 10 to 15 feet in length and more than a foot in depth. These beds were observed in pockets along the perimeter of the pools and in small backwaters. They were scoured away during heavy rains but usually were re-established within a short time.

Filamentous bacteria covered most of the rocks in the riffle areas for approximately 1,200 feet below the outfall. Sparse growths of blue-green algae (Phormidium) were observed on the rocks at the outfall; however, few algae of any kind were noted in the 2,400-foot stretch immediately below the outfall. The sparse growth may be the result of heavy, terrestrial shade. Below this point, direct sunlight reached the stream and a luxuriant growth of filamentous green algae (Cladophora and Hydrodictyon) persisted for approximately 900 feet above station A5 during the August 1961 survey, but was not observed during the March and May surveys of 1962. Fewer algal growths were observed in Stream M above and below the junction with Stream A than in Stream A.

Figure 3 shows the results of the biological survey of Stream A for study periods in August 1961 and in March and May 1962. At each station benthic forms and fish tolerant of organic pollution are compared with clean-water forms. In general, this stream is definitely out of biotic balance in the upper reach because of degradation by plant effluent; however, there is marked recovery of aquatic life downstream because of the re-aeration ability of the stream.

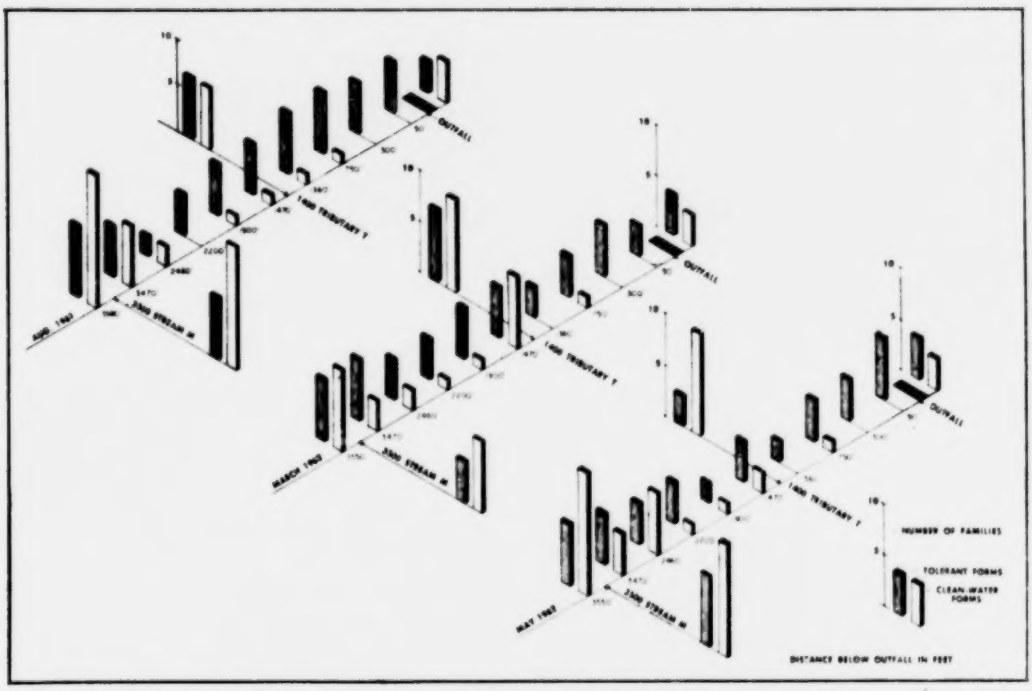


Figure 3. Bottom fauna and fish, number of families per station on Streams A and M and Tributary T.

Clean-water forms were never collected at the first two stations below the outfall during the three surveys. Faunal populations from above the outfall, from a tributary entering below station A3a, and from Stream M above its confluence with Stream A showed a greater diversification of forms than did Stream A. The presence of clean-water forms at Station M2 demonstrated the dilutional effect of Stream M on the benthos below the junction.

The variety of organisms collected from the stations on Tributary T and Stream M would be expected in an unpolluted stream.

Prior to the installation and operation of the sewage treatment plant, a fish population, mostly minnows had been observed by local residents in Stream A. During the August 1961 and March 1962 surveys no fish were observed. A few young-of-the-year bluegills were taken 2,400 feet below the outfall in May 1962; however, it is believed that these fish were washed from a farm pond on Tributary T during a heavy rainfall.

The fish population was abundant in Stream M both above and below Stream A; it consisted of creek chubs, orangethroated darters, largemouth black bass, fathead minnows, and blacknosed dace. Although the fish population potentially could have migrated upstream into the Stream A, this had not occurred; and, since no physical obstruction hampered migration, some component of the water probably presented a barrier.

The biota in Tributary T was in balance for all three surveys. The organisms that drifted or migrated into Stream A from Tributary T during August 1961 and May 1962 did not persist. In March 1962 a marked seasonal change occurred in Stream A downstream from the tributary; some organisms survived for a period, but not long enough for the organisms to become established at downstream stations. The longer survival time in March 1962 may be attributed to higher DO, lower temperature, and a more dilute concentration of chemical constituents in the stream.

These studies indicate that at times Stream A receives excessive loads of poor quality effluent from the treatment plant that causes biological degradation and could foster the development of aquatic nuisances. The rate of biological recovery, therefore, was slow and incomplete for Stream A. Below the junction of Stream A with Stream M, biological recovery was rapid.

PLANT B

Flow variations were not as great in Plant B as in Plant A. The average daily flow varied from 18,000 to 71,500 gpd; the majority of the values ranged between 20,000 and 40,000 gpd (Table 3). Since periods of poor effluent quality correlate with periods of high solids losses, solids losses from Plant B were greater during periods of above average flow.

Concentrations of total suspended solids and volatile suspended solids in the plant effluent exceeded the corresponding values in the raw sewage in three daily composite samples (December 16, March 7, and March 9). Suspended solids in the daily composite samples of raw sewage varied from 67 to 610 milligrams per liter and in the effluent from 12 to 1500 milligrams per liter. The maximum suspended-solids reduction efficiency was 98 percent.

BOD in daily composite samples varied from 140 to 380 milligrams per liter in the raw sewage and from 6 to more than 71 in the plant effluent. The BOD reduction efficiency in the plant varied from no reduction to 98 percent. The efficiency was above 85 percent for 25 of the 28 days of sampling and above 90 percent for 17 days.

Generally the pH and DO of the mixed liquor were maintained in favorable ranges, although there were a few hourly periods when the DO dropped to zero. Solids losses from the plant tended to increase when denitrification occurred in the system. Nitrification was high within the plant except during May.

Coliform bacteria in the effluent varied from 64,800 to 9,820,000 per 100 milliliters for the study period. Plant reduction efficiency varied from 43 to more than 99 percent, with 26 values above 80 percent, 21 values above 90 percent, and 16 values above 97 percent. The stream could become a health hazard to residents in the area, especially to children who play around and in the water.

STREAM B

Stream B is from 2 to 6 feet in width, has low banks of medium slope, has a fall of 30 feet per mile, and is characterized by riffles interspersed with narrow, shallow pools. A maximum depth of 3 feet was found in a pool area, but only an inch or two of water was present in riffle areas. The varied composition of the stream bed consists of a mixture of rocks, gravel, sand, silt, clay, and plant detritus. Tree overhang shades the greater part of the reach studied and thus prevents optimum algal growths despite the presence of other requisites for such growth.

Four collections were made on this stream during the study year, August and December 1961 and March and May 1962 (Figure 4). In all collections the number of clean-water forms decreased below the sewage-plant outfall, but increased rapidly in relation to the distance downstream. The greatest fluctuation in number of forms collected throughout the year, or for any one collection, occurred in the clean-water forms. The number of tolerant forms was very stable.

The number of forms collected during August and December 1961 and March 1962 were very similar. The greatest variation was in the number of individuals per form. A seasonal variation was noted during December when two forms, the aquatic sow bug and the scud, were the dominant organisms at every station as a result of good fall reproduction and decreased predation.

During the three earlier surveys, small amounts of inert sludge were observed at a maximum distance of 400 feet below the outfall. In May 1962, however, a blanket of partially decomposed organic sludge was observed 3,200 feet below the outfall. This sludge caused a pronounced decline in the number of clean-water forms at stations below the outfall, compared with the number in the region above the outfall. The number of individuals per clean-water form were few in May, compared with the number during the three earlier collections.

Four species of fish were collected from this stream during each survey. Three of these, green sunfish, fathead minnows, and creek chubs, were found within 50 feet below the outfall during

the first three collections; however, fish were not observed or collected below the outfall for approximately 1,900 feet during the fourth survey. Another species collected during this study was the common white sucker; however, it was never collected closer than 4,500 feet below the outfall because of the very shallow depth above this point.

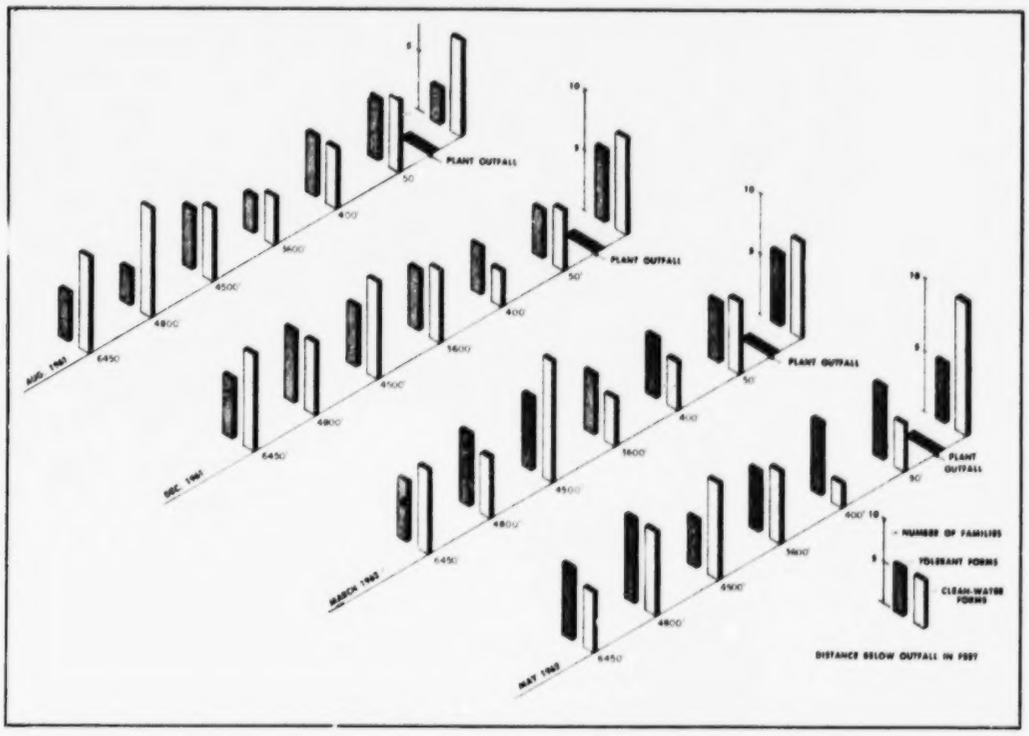


Figure 4. Bottom fauna and fish, number of families per station on Stream B.

The greater sludge load on the stream during the May survey increased the BOD, compared with that during the previous study periods, and as a result the DO during the May study was the lowest for all study periods. The average of the minimum daylight DO during May 1962 was 1.7 milligrams per liter, compared with the August 1961 minimum average of 3.6 milligrams per liter. Diurnal fluctuations in stream DO for a 24-hour period during May (17 and 18) are shown in Figure 5. The lower DO during May had a definite adverse effect on the number of clean-water forms.

Algal growth within the study reach (6,450 feet below the outfall) appeared to be minimal because of shade from terrestrial plants. Prior to new road construction that changed the waterway and reduced the length of the study reach, downstream portions of the stream exposed to direct sunlight supported luxuriant patches of Cladophora. Such algal mats can produce obnoxious odors during decomposition.

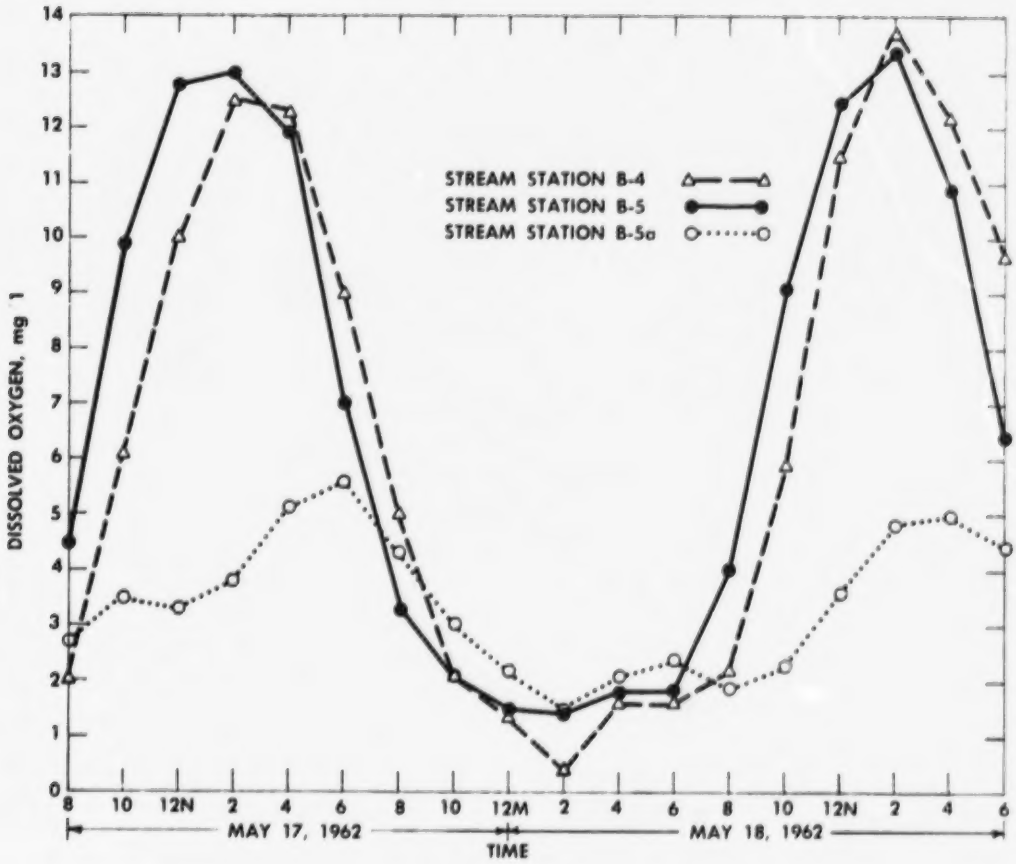


Figure 5. Diurnal fluctuations of dissolved oxygen in Stream B.

Larvae of pest mosquitoes known to reach tremendous numbers in association with organic pollution were not present in the free-flowing stream.

Though somewhat biologically degraded below the treatment-plant outfall, Stream B had a benthic and fish population that recovered rapidly within a short distance downstream during the August, December, and March study periods. During the May study period the zone of biological degradation extended farther downstream. This variation in stream recovery shows the relationship that exists between the waste load received by the stream and the diversity of aquatic fauna.

DISCUSSION

Extreme fluctuations in sewage flow are major causes of excessive loss of solids in an extended-aeration plant effluent. Such fluctuations may result from a number of causes: variation of activity in the facility served, entrance of storm water into the system by various means, and use of constant-speed raw-sewage pumps with capacities greatly in excess of the normal flow rate. Also, when available DO in a sedimentation basin is depleted, denitrification occurs and solids may rise and be carried into the plant effluent.

The lack of plant facilities for control of mixed-liquor suspended solids accelerates the loss of solids in plant effluent. This condition, with or without flow fluctuations, results in discharge of large quantities of solids to the receiving stream. Extremely high solids losses can occur if the sludge collection or return system fails. These mechanical factors necessitate adequate maintenance and daily inspection. Any of these conditions occurring alone or in combination results in poor plant performance.

Fluctuations are inherent in the performance of the basic plant; however, the basic plant can be supplemented with additional facilities to maintain efficiency within a high range. Several adaptations to achieve this purpose are outlined in Figure 6. Two approaches to this problem are solids control within the plant and effluent-polishing techniques to remove suspended solids.

In-plant solids may be controlled by routine wasting of sludge to a holding tank, drying bed, or an aerobic stabilization tank. A plant in Michigan was successfully operated by controlling the solids.[5] The decision to waste sludge could be made from a simple settling test or when the DO in the mixed liquor drops below 1 milligram per liter.

Sand beds for sludge drying are effective during warm-weather operation. There is evidence* that during periods of low-temperature operation the waste sludge does not dry readily without additional stabilization in a separate tank. Digestors should be operated at a temperature greater than 10° C for satisfactory performance. The volatile-solids content of waste sludge from a basic plant is greater during periods of low-temperature operation.

*Ludzack, F. J. Observations on bench scale studies of extended aeration sewage treatment. Presented at the Ohio Water Pollution Conference, Toledo, Ohio, June 13, 1963.

Sand filters designed for slow filtration at a rate of 10 gallons of effluent per square foot per day are being used successfully in several installations. Division of the filtration area into several beds is necessary for proper operation and maintenance.

Short-time detention in a holding pond effectively intercepts suspended solids from a basic plant. The most effective detention time depends upon the objectives, the climate, the organic load, algal development, and benthic activity in the pond. Preliminary studies of a pond near Cincinnati showed good results at detention times of 3 to 5 days with a daily average temperature range of 11° to 13° C in the pond and 2° to 9° C in the air. The BOD of daily composites of pond effluent ranged from 4 to 11 milligrams per liter, and suspended solids from 11 to 19 milligrams per liter (Appendix E). Profuse algal growths developed during 5-day detention, indicating that longer detention times would be undesirable.

Studies of the effects of holding time, temperature, algal growth, sludge accumulation, and benthic organisms, and their interrelated effects on effluent quality are required for development of pond design data.

The effect of temperature on the efficiency of basic extended-aeration plants is frequently difficult to determine since, at times, other factors are the predominant influence on plant performance. At Plant A, for example, average BOD reductions were 83, 89, and 42 percent and average suspended-solids reductions were 77, 66.

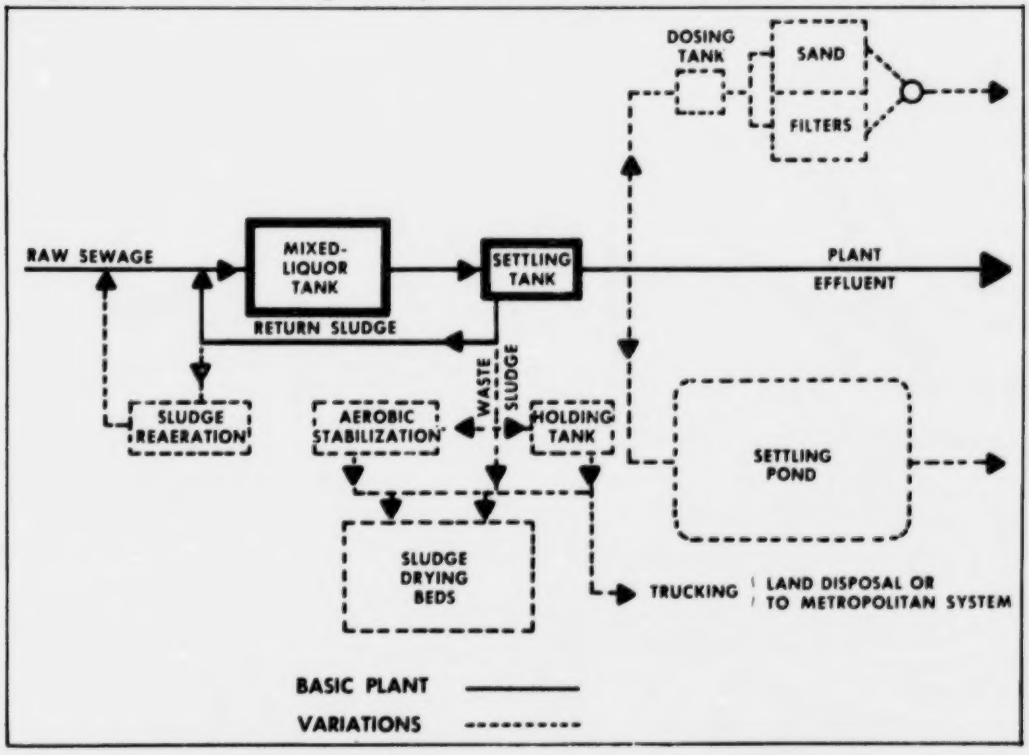


Figure 6. Variations of extended-aeration process.

and 0 percent for the 3 periods studied. Average BOD reduction was greatest during March, whereas suspended-solids results were best in August. In this case, the change from the use of one aeration basin and settling basin in August to two of each in March and May and the extreme fluctuations in raw sewage flow were the prime factors affecting Plant A. Plant B data indicate possible temperature effects, since the August and May results were better than those of March (Appendix B).

Temperature effects on operation are more pronounced and can be better evaluated when other factors influencing the unit can be held near "steady-state." In bench-scale studies at the Sanitary Engineering Center, Ludzack* found that low temperature adversely affects extended-aeration plant performance. He found that at 21° to 25° C, COD reduction was over 90 percent, with wastage of 5 percent mixed-liquor suspended solids per week to maintain a mixed-liquor suspended solids concentration of 6,000 milligrams per liter. The waste sludge was 60 percent volatile and drained and air-dried readily on sand beds.

At 10° C, COD reduction was about 90 percent, with wastage of 10 to 20 percent mixed-liquor suspended solids per week to maintain mixed-liquor suspended solids a concentration of 5,000 milligrams per liter. The waste sludge was 65 percent volatile and dried fairly well, but much more time was required than for sludge produced at higher temperatures.

At 5° C, COD reduction was about 84 percent, with wastage of 20 percent mixed-liquor suspended solids per week to maintain a mixed-liquor suspended solids concentration of 5,000 milligrams per liter. Waste sludge was 75 to 80 percent volatile and would not drain on sand beds. This indicates that during winter operation waste sludge should be disposed of by other means or further stabilized before it is placed on sand beds. Reduction of the volatile content of waste sludge by storage in anaerobic or aerobic stabilization tanks improves its dewatering characteristics.

To determine the relationship of BOD and nitrogen, the results of a number of long-term BOD tests were compared with nitrogen data. The long aeration period in extended-aeration plants usually results in substantial or complete nitrification in the aeration tank. A nitrogenous oxygen demand is exerted by nitrifying bacteria in the conversion of ammonia to nitrite and thence to nitrate. Little buildup of nitrite occurs because it is oxidized to nitrate about as rapidly as it is formed. In the absence of toxic wastes, ammonia and nitrate data indicate the amount of

* Ibid.

nitrogenous oxygen demand that may be encountered in BOD tests or in a receiving stream.

In August, the average ammonia concentration in the effluent of Plant A was 37 milligrams per liter, whereas the average nitrate concentration was only 0.01 milligrams per liter. In March the nitrification reaction was more completely satisfied in the treatment plant and, therefore, probably had a smaller effect on BOD values and the DO in the receiving stream. More DO was present in the mixed liquor in March, as indicated by the more complete nitrification observed in the plant and in the stream.

When sludge is allowed to remain in a settling basin with a low DO level, the nitrates present may be used as a source of oxygen. Denitrification releases nitrogen gas, and the sludge is lifted by the escaping gas and discharged in the effluent. Visual observations at Plant B confirm that solids occasionally rise as a result of denitrification and are discharged over the weir.

Exclusive of periods of slug discharges of solids, the effluents from the two plants usually contained less than 30 milligrams of suspended solids per liter and 35 milligrams of 5-day BOD per liter, and frequently both concentrations were 20 milligrams per liter or less.

To study the relationship between the carbonaceous and nitrogenous oxygen demand of both the influent and effluent, long-term BOD tests were run on samples from both plants. One set of long-term BOD data from samples collected at Plant B is shown in Figure 7. In these particular samples, the influent BOD was primarily carbonaceous for the first 11 days. Following the eleventh day, the nitrogenous oxygen demand exerted a significant effect on the BOD curve. The carbonaceous stage in the effluent samples was nearly complete at the beginning of the BOD test, and after 2 days the nitrification reaction became predominant. In this case, the 5-day BOD's would not give an accurate picture of plant efficiency because both the nitrogenous demand and carbonaceous demand of the effluent would be compared with only the carbonaceous demand of the influent. Rather than measuring a BOD reduction of 97 percent based on the estimated 5-day carbonaceous effluent demand, a BOD reduction of only 87 percent is indicated by the combined (nitrogenous-carbonaceous) 5-day effluent BOD. A more correct evaluation of the process efficiency would be based on a comparison of the ultimate, or carbonaceous plus nitrogenous, demands.

The other influent samples collected at the two plants always showed the two distinct stages shown in Figure 7; however, the effluent samples did not. Some effluent samples had a low first stage

and a high second stage (Figure 7); whereas, others were well into nitrification and had only a relatively high initial stage.

Nitrogen analyses before the after incubation would determine the amount of oxygen used in the oxidation of nitrogenous compounds. For example, the effluent data gathered in May at Plant B (Table 3) shows that nitrification was not completed in the plant and that the nitrogenous oxygen demand comprised a significant portion of the effluent BOD.

Long-term BOD analyses to supplement the 5-day BOD test periodically permit more comprehensive evaluation of extended-aeration plant efficiency.

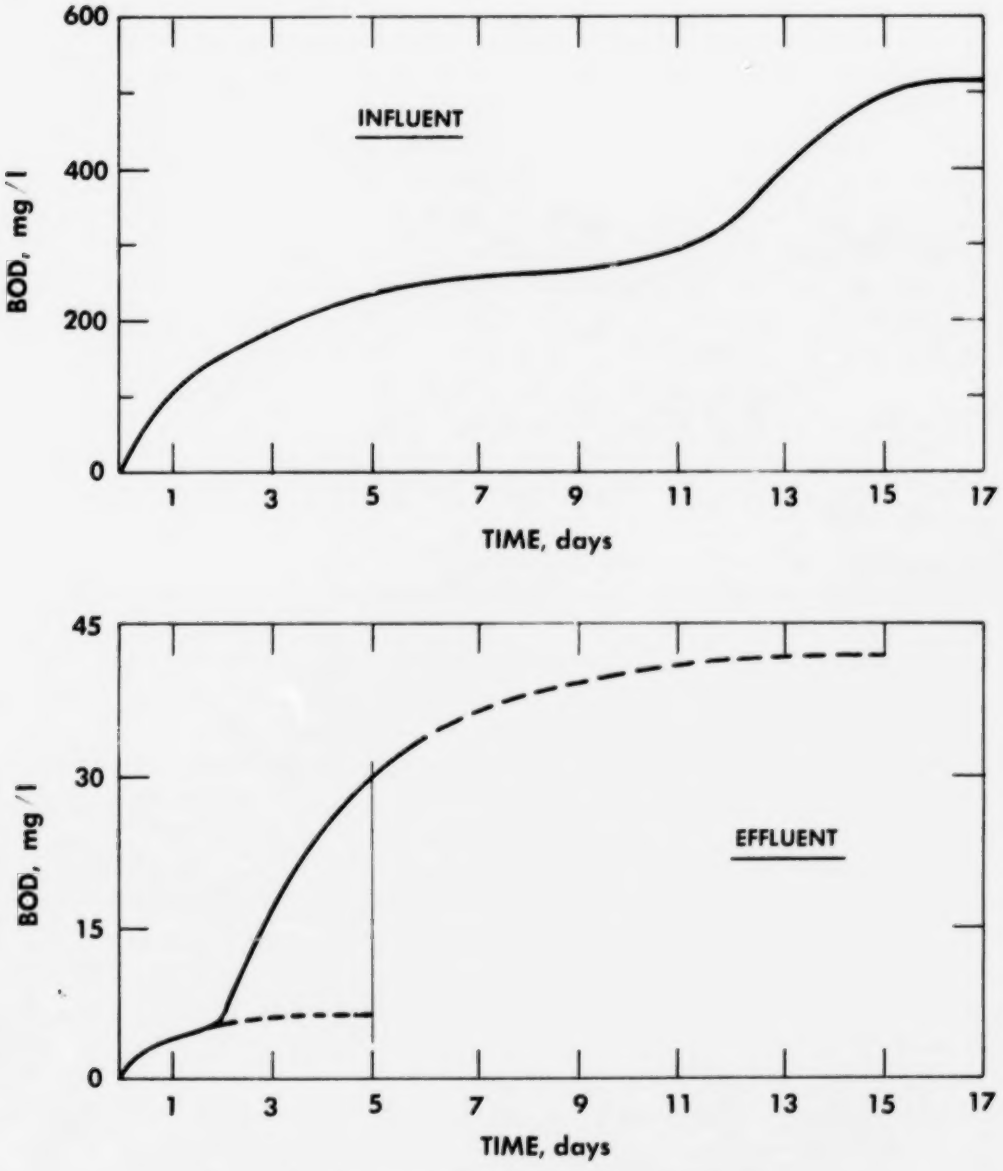


Figure 7. Results of long-term BOD analyses, Plant B.

CONCLUSION

The increased use of extended-aeration plants, from 1,200 in 1960 to more than 2,600 in 1962, shows the acceptance and growth of this method of treatment. Sanitary engineering evaluation of proposed plant sites and environmental conditions is, of course, of paramount importance in the design and location of these plants. Several general conclusions about plant design and operation drawn from this study and earlier studies follow:

1. The quality of effluent from extended-aeration plants is primarily related to the concentration of solids in the effluent and the degree of nitrification effected in the plant.

2. Basic extended-aeration plants (no solids control) cannot maintain high BOD and suspended-solids reduction efficiencies for long periods of continuous operation.

3. The build up of suspended solids in the mixed liquor is an inherent characteristic of the extended-aeration process. In the basic plant (no solids control), BOD and suspended-solids reduction efficiencies vary greatly.

4. The discharge of large amounts of suspended solids in plant effluent usually coincides with surges in flow rate. Raw sewage lift stations ahead of extended-aeration plants are one cause of serious fluctuations in flow rate.

5. Denitrification in the system can cause loss of suspended solids in the effluent, with or without surges in flow rate.

6. Modification of the basic plant by addition of sludge-wasting facilities for control of mixed-liquor suspended solids or by addition of effluent-polishing units can provide BOD reduction efficiencies above 90 percent for long periods of continuous operation.

7. Variations in the nature of the oxygen demand of plant influent and effluent indicate a significant error is possible when plant BOD reduction efficiencies are based on 5-day 20° C BOD without consideration of the nitrogenous oxygen demand of the effluent.

8. Although effluent solids from normal plant operation are relatively inert, a low-rate oxygen demand is created if solids accumulate as a sludge bank in the stream.

Specific conclusions drawn from the study of basic plants A and B and streams A and B, and a later study of an effluent pond follow:

1. Settleable solids in the effluents of basic plants A and B formed sludge deposits in the intermittent watercourses receiving the effluent. The water flowing above the sludge deposits was usually clear, with dissolved oxygen present. The increase in the number of benthic forms, in relation to distance downstream from the plant outfall, depended on the degree of solids deposition. The nuisance potential of sludge deposits from basic plants is greater than from plants with positive solids control.

2. Studies of a pond at plant B designed for 3 day's retention of total daily effluent flow showed the effluent quality was improved when the pond was operated at a pond temperature of 11° to 13° C and an air temperature of 2° to 9° C. Additional study of effluent ponds is needed to evaluate their effectiveness under variable geographic conditions, organic load, algal development, and benthic activity.

3. The unshaded reaches of streams A and B produced profuse attached algal growths, indicating high nutrient levels in the streams.

4. Electric power costs ranged from about 1 to 1-1/2 cents per 1,000 cubic feet of air for all uses in extended-aeration plants A and B.

ACKNOWLEDGMENT

This study of "Extended-Aeration Plants and Intermittent Watercourses" evaluates the principal points of interest of state sanitary engineers as reflected by their reactions to the 1960 report, "Extended-Aeration Sewage Treatment, A Preliminary Evaluation."

The objectives of these studies were influenced by requests for information by the Conference of State Sanitary Engineers and the Upper Mississippi River-Great Lakes Board of Sanitary Engineers.

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APPENDIX

A. SUMMARY OF DATA FROM SEWAGE TREATMENT PLANT A

B. SUMMARY OF DATA FROM SEWAGE TREATMENT PLANT B

C. BENTHIC ORGANISMS AND FISH, STREAM A

D. BENTHIC ORGANISMS AND FISH, STREAM B

E. SUMMARY OF EXTENDED-AERATION PLANT EFFLUENT POND DATA

TABLE A2. SUMMARY OF MIXED LIQUOR DATA FROM SOUTH TANK AT SEWAGE TREATMENT PLANT A

Date	pH, max.	pH, min.	Avg temp, °C	Avg DO, mg/l	Suspended solids, mg/l	Volatile suspended solids, mg/l	Settleability (30 min), ml/l
Aug. '61							
15		7.5[a]	24.5	0.6	7,170	3,770	240
16		7.7	23.6	0.3	7,980	4,070	255
17		7.6	23.8	0.8	8,090	4,320	270
18		7.6	23.8	0.5	7,940	4,170	290
19		7.4	23.5	0.8	7,360	4,350	225
20		7.4	23.0	0.8	8,470	4,440	297
21		7.4	22.8	0.9	8,240	4,340	285
Max.		7.7	24.5	0.9	8,470	4,440	297
Min.		7.4	22.8	0.3	7,170	3,770	225
Avg			23.6	0.7	7,890	4,210	266
Mar. '62							
15	7.4	6.7	10.2	1.4	3,020	1,880	137
16	7.4	7.2	9.7	1.4	2,680	1,520	142
17	7.6	7.0	10.3	1.5	2,760	1,660	130
18	7.6	7.1	10.5	1.6	3,180	1,940	155
19	7.3	7.2	11.8	1.0	3,440	2,320	155
20	7.2	7.1	12.3	1.1	3,200	1,960	155
21	7.6	7.0	12.0	2.4	3,180	1,860	130
Max.	7.6		12.3	2.4	3,440	2,320	155
Min.		6.7	9.7	1.0	2,680	1,520	130
Avg			11.0	1.5	3,070	1,880	143
May '62							
22	7.6	6.8	21.0	0.7	6,080	3,420	835
23	7.5	7.2	21.5	0.7	6,060	3,500	880
24	7.5	7.1	20.7	0.8	6,380	3,700	470
25	7.5	7.1	20.0	0.8	6,240	3,400	875
26	7.3	6.9	19.5	0.8	6,160	2,840	370
27	7.3	7.2	19.7	1.3	5,240	2,220	270
Max.	7.6		21.5	1.3	6,380	3,700	880
Min.		6.8	19.5	0.7	5,240	2,220	270
Avg			20.4	0.8	6,030	3,180	617

[a] pH on 24-hr composite for August

APPENDIX A

TABLE A1. SUMMARY OF RAW SEWAGE DATA AT SEWAGE TREATMENT PLANT A

Date	Flow, gpd	pH, max.	pH, min.	Avg temp, °C	BOD, mg/l	Total solids, mg/l	Total volatile solids, mg/l	Suspended solids, mg/l	Volatile suspended solids, mg/l	ABS, mg/l	Coliform per 100 ml
Aug. '61											
15	21,600		7.1[a]	22.5	400			350	250		90,000,000
16	21,300		7.4	23.0	330			270	220		69,700,000
17	25,300		7.8	22.8	550			560	340		111,000,000
18	21,400		7.4	24.0	370			350	240		62,100,000
19	24,800		7.5	23.7	390			350	110		54,100,000
20	19,400		7.4	22.0	340			350	220		100,000,000
21	19,700		7.6	22.2	490			550	300		53,900,000
Max.	25,300		7.8	24.0	550			560	340		111,000,000
Min.	19,400		7.1	22.0	330			270	110		53,900,000
Avg	21,900			22.9	410			400	240		77,300,000
Mar. '62											
15	68,900	8.1	7.1	11.7	340	720	350	200	200	10.6	13,200,000
16	66,000	8.6	7.7	11.8	370	710	250	170	160	14.1	23,600,000
17	65,000	8.2	7.6	11.8	380	700	270	120	110	15.8	24,500,000
18	61,400	8.2	7.3	11.8	390	710	400	190	190	10.2	33,200,000
19	64,200	8.1	7.6	12.8	340	1000	640	520	520	12.5	28,800,000
20	151,100	8.2	7.2	12.8	250	860	420	370	220	7.2	27,300,000
21	247,800	7.8	7.2	11.7	82	1120	260	760	170	0.8	2,500,000
Max.	247,800	8.6		12.8	390	1120	640	760	520	15.8	33,200,000
Min.	61,400		7.1	11.7	82	700	250	120	120	0.8	2,500,000
Avg	103,500			12.1	310	830	370	330	220	10.2	21,900,000
May '62											
22	67,400	8.1	7.4	17.6	280	960	440	250	180		32,600,000
23	51,600	8.1	7.6	17.8	330	990	470	260	230		38,100,000
24	47,600	8.2	7.5	17.0	360	1200	640	86	40		45,100,000
25	79,700	8.1	7.4	17.4	220	1020	370	480	220		23,700,000
26	154,900	8.2	7.2	17.6	130	1160	350	670	140		32,300,000
27	186,700	7.8	7.2	17.7	110	1010	290	560	130		11,500,000
Max.	186,700	8.2		17.8	360	1200	640	670	230		45,100,000
Min.	47,600		7.2	17.0	110	960	290	86	40		11,500,000
Avg	98,000			17.5	240	1060	420	380	160		30,600,000

[a] pH on 24-hr composite for August

TABLE A4. SUMMARY OF PLANT EFFLUENT DATA AT SEWAGE TREATMENT PLANT A

Date	pH, max.	pH, min.	Avg temp, °C	Avg DO, mg/l	BOD, mg/l	Total solids, mg/l	Total volatile solids, mg/l	Suspended solids, mg/l	Volatile suspended solids, mg/l	Settleable solids, (1 hr Imhoff Cone), ml/l	ABS, mg/l	NH_3, mg/l	NO_2, mg/l	NO_3, mg/l	PO_4, mg/l	Coliform per 100 ml
Aug. '61																
15	7.7[a]		23.3	0.2	55			110	77	< 0.1	9.6	36.0	0.016	0.04	52	5,050,000
16	7.8		23.3	0.5	74			85	65	< 0.1	4.3	37.0		0.00	76	5,830,000
17	7.7		23.5	0.4	70			100	89	< 0.1	6.6	39.0	0.010	0.01	66	7,130,000
18	7.7		23.5	0.8	66			78	67	< 0.1	8.8	43.0	0.012	0.01	52	15,400,000
19	7.7		23.7	0.7	66			96	79	< 0.1	7.2	35.5	0.008	0.01	54	26,000,000
20	7.6		22.6	0.5	74			75	55	< 0.1	6.8	36.0	0.006	0.00	46	39,000,000
21	7.6		22.4	0.5	69			96	68	< 0.1	11.8	35.5	0.006	0.00	54	18,500,000
Max.	7.8		23.7	0.8	74			110	89	< 0.1	11.8	43.0	0.016	0.04	76	39,000,000
Min.	7.6		22.4	0.2	55			75	55	< 0.1	4.3	35.5	0.006	0.00	46	5,050,000
Avg			23.2	0.5	68			91	71		7.9	37.4	0.010	0.01	57	16,700,000
Mar. '62																
15	7.8	7.0	9.9	1.4	19	600	230	9	8	< 0.1	5.4	0.34	0.580	18.8	37	399,000
16	7.7	7.0	9.8	1.5	21	540	140	4	3	< 0.1	6.4	0.90	0.580	26.2	39	305,000
17	7.8	6.8	10.0	1.1	16	570	160	13	12	< 0.1	7.0	1.24	0.644	26.4	42	228,000
18	7.5	6.7	10.4	1.1	15	620	280	20	20	< 0.1	6.1	1.82	0.600	27.2	44	257,000
19	7.9	7.1	11.8	1.0	15	610	360	14	13	< 0.1	6.2	1.88	0.740	27.2	42	267,000
20	7.3	7.1	12.4	0.8	28	590	230	200	150	1.5	4.0	0.78	0.500	20.8	37	525,000
21	8.0	7.0	11.6	1.6	120	850	370	530	250	21.0	1.1	0.93	0.260	14.0	30	5,180,000
Max.	8.0		12.4	1.6	120	850	370	530	250	21.0	7.0	1.88	0.740	27.2	44	5,180,000
Min.		6.7	9.8	0.8	15	540	140	4	3	< 0.1	1.1	0.34	0.500	14.0	30	228,000
Avg			10.8	1.2	33	630	250	110	65		5.2	1.13	0.558	22.9	39	1,023,000
May '62																
22	7.7	7.2	21.4	0.9	8	610	160	7	7	< 0.1	8.0	5.56	0.018	0.20	51	669,000
23	7.7	7.2	21.7	0.8	40	640	170	39	31	0.8	7.4	5.56	0.028	0.25	51	560,000
24	8.1	7.2	20.6	0.8	12	630	170	5		< 0.1	8.8	5.50	0.028	0.23	50	1,180,000
25	7.7	7.2	20.0	0.6	19	660	160	10	10	< 0.1	8.6	3.80	0.023	0.35	51	1,540,000
26	7.4	6.6	19.5	0.6	500	2200	960	1800	870	106	6.0	2.60	0.012	0.23	75	2,410,000
27	7.4	7.2	19.1	0.6	250	1060	390	610	250	30	4.4	1.40	0.066	1.10	38	2,080,000
Max.	8.1		21.7	0.9	500	2200	960	1800	870	106	8.0	5.56	0.066	1.10	75	2,410,000
Min.		7.2	19.1	0.6	8	610	160	5	7	< 0.1	4.4	1.40	0.012	0.20	38	560,000
Avg			20.4	0.7	140	970	330	410	230		7.2	4.07	0.029	0.39	53	1,407,000

[a] pH on 24-hr composite for August

TABLE A3. SUMMARY OF MIXED LIQUOR DATA FROM NORTH TANK AT SEWAGE TREATMENT PLANT A

Date	pH, max.	pH, min.	Avg temp, °C	Avg DO, mg/l	Suspended solids, mg/l	Volatile suspended solids, mg/l	Settleability (30 min), ml/l
Aug. '61[a]							
Mar. '62							
15	7.4	7.1	10.0	3.5	2,840	1,740	135
16	7.8	7.2	10.2	2.8	2,720	1,520	140
17	7.5	7.1	10.3	2.7	2,860	1,820	138
18	7.3	7.1	10.5	3.2	3,160	2,000	153
19	7.3	7.1	12.0	2.1	3,380	2,400	149
20	7.6	7.0	12.3	1.8	3,760	2,320	160
21	7.3	6.9	11.3	3.9	3,440	1,800	125
Max.	7.8		12.3	3.9	3,760	2,400	160
Min.		6.9	10.0	1.8	2,720	1,520	125
Avg			10.9	2.9	3,170	1,940	143
May '62							
22	7.5	7.4	21.2	0.5	6,040	3,360	910
23	7.5	7.3	21.7	0.7	6,120	3,380	465
24	7.7	7.2	20.7	0.7	5,980	3,480	490
25	7.4	7.2	18.8	0.7	6,260	3,420	900
26	7.4	6.9	19.5	0.9	6,620	3,100	400
27	7.3	7.2	19.0	1.0	5,560	2,280	285
Max.	7.7		21.7	1.0	6,620	3,480	910
Min.		6.9	18.8	0.5	5,560	2,280	285
Avg			20.2	0.8	6,100	3,170	575

[a] North Tank not in operation in August 1961

TABLE A6. SUMMARY OF DATA FROM STATION A4 ON STREAM A

Date	pH, max.	pH, min.	Avg temp, °C	Avg DO, mg/l	BOD, mg/l	Suspended solids, mg/l	Volatile suspended solids, mg/l	ABS, mg/l	NH_3, mg/l	NO_2, mg/l	NO_3, mg/l	PO_4, mg/l
Aug. '61												
15		7.8[a]	21.2	5.2	18	50	12	22.4	8.4	0.580	0.60	24
16		7.9	21.5	5.0	18	61	17	21.8	11.0	1.280	8.40	28
17		7.9	21.4	5.0	18	32	9	9.6	11.4	1.360	7.60	26
18		7.9	22.2	4.9	19	64	14	9.4	12.4	1.340	7.20	26
19		7.8	21.8	4.6	20	64	22	8.2	12.6	1.400	6.00	23
20		7.8	20.9	4.3	12	69	12	8.6	9.5	1.650	6.80	20
21		7.8	19.6	4.7	25	75	20	8.4	11.0	1.500	5.60	44
Max.		7.9	22.2	5.2	25	75	22	22.4	12.6	1.650	8.40	44
Min.		7.8	19.6	4.3	12	32	9	8.2	8.4	0.580	0.60	20
Avg			21.2	4.8	19	59	15	12.6	10.9	1.300	6.03	27
Mar. '62												
15	8.5	7.8	5.0	12.5	2	11	10	1.1	0.34	0.052	1.24	7
16	8.2	7.7	3.4	12.6	2	2	2	1.5	0.34	0.043	1.72	8
17	8.2	7.8	4.6	12.3	3	8	7	1.5	0.25	0.052	3.40	9
18	8.2	7.8	5.3	12.2	5	9	8	1.8	0.22	0.050	3.60	9
19	8.2	8.0	7.5	11.1	2	11	11	1.6	0.24	0.064	3.60	10
20	8.5	8.0	10.3	10.8	3	29	27	1.4	0.14	0.044	2.74	8
21												
Max.	8.5		10.3	12.6	5	29	27	1.8	0.34	0.064	3.60	10
Min.		7.7	3.4	10.8	2	2	2	1.1	0.14	0.044	1.24	7
Avg			6.0	11.9	3	12	11	1.5	0.25	0.052	2.72	8
May '62												
22	10.2	7.6	20.4	7.6	4	55	10	3.6	0.52	0.076	1.35	22
23	8.1	7.3	21.4	7.3	3	48	16	3.1	0.12	0.011	1.30	20
24	8.1	7.9	20.1	7.3	3	34	12	3.4	0.10	0.006	1.10	20
25	7.9	7.8	18.7	8.2								
26	8.1	7.7	18.0	8.8								
27	7.9	7.6	17.7	8.8								
Max.	10.2		21.4	8.8	4	55	16	3.6	0.52	0.076	1.35	22
Min.		7.3	17.7	7.3	3	34	10	3.1	0.10	0.006	1.10	20
Avg			19.4	8.0	3	46	13	3.4	0.25	0.031	1.25	21

[a] pH on 24-hr composite for August

TABLE A5. SUMMARY OF DATA FROM STATION A3a ON STREAM A

Date	pH, max.	pH, min.	Avg temp, °C	Avg DO, mg/l	BOD, mg/l	Suspended solids, mg/l	Volatile suspended solids, mg/l	ABS, mg/l	NH_3, mg/l	NO_2, mg/l	NO_3, mg/l	PO_4, mg/l	Coliform per 100 ml
Aug. '61													
15													
16													
17													
18		7.8[a]	21.3	5.0	28	65	33	6.8	35.0	0.540	0.92	39	
19		7.7	21.7	3.7	33	16	11	7.8	28.0	0.520	0.80	33	
20													
21													
Max.		7.8	21.7	5.0	33	65	33	7.8	35.0	0.540	0.92	39	
Min.		7.7	21.3	3.7	28	16	11	6.8	28.0	0.520	0.80	33	
Avg			21.5	4.4	31	40	22	7.3	31.5	0.530	0.86	36	
Mar. '62													
15	8.3	7.2	5.3	12.3	4	9	3	2.6	0.90	0.180	12.4	14	68,400
16	8.3	6.3	4.7	11.2	7	2	2	3.6	0.96	0.190	15.6	17	66,000
17	8.5	7.5	6.1	11.0	6	9	9	4.1	0.88	0.220	20.0	19	58,600
18	8.4	8.0	6.9	11.6	5	11	10	4.1	0.89	0.200	19.0	20	58,600
19	8.2	7.2	9.3	10.6	8	23	21	4.1	0.68	0.250	20.0	18	116,000
20	8.3	7.9	11.3	10.7	5	55	15	2.8	0.58	0.180	16.8	16	55,000
21													
Max.	8.5		11.3	12.3	8	55	21	4.1	0.96	0.250	20.0	20	116,000
Min.		6.3	4.7	10.6	4	2	2	2.6	0.58	0.180	12.4	14	55,000
Avg			7.3	11.2	6	18	8	3.0	0.70	0.174	14.8	17	70,400
May '62													
22	8.1	7.1	20.3	5.7	16	73	18	6.1	1.41	0.240	1.70	33	139,000
23	8.8	7.1	20.7	5.4	5	30	9	5.4	0.48	0.200	2.05	30	30,400
24	8.1	7.6	19.0	5.8	5	23	13	6.2	0.28	0.125	2.20	31	29,000
25	7.9	7.9	17.5	7.1									
26	7.9	7.3	18.5	6.7									
27	7.9	7.6	18.0	7.4									
Max.	8.8		20.7	7.4	16	73	18	6.2	1.41	0.240	2.20	33	139,000
Min.		7.1	17.5	5.4	5	23	9	5.4	0.28	0.125	1.70	30	29,000
Avg			19.0	6.4	9	42	13	5.9	0.72	0.188	1.98	31	66,100

[a] pH on 24-hr composite for August

TABLE A8. SUMMARY OF DATA FROM STATION M1 ON STREAM M

Date	pH, max.	pH, min.	Avg temp, °C	Avg DO, mg/l	BOD, mg/l	ABS, mg/l
Mar. '62						
15	8.9	8.3	3.8	13.4	2	0.1
16	8.6	8.3	2.7	13.8	1	0.2
17	8.6	8.4	4.1	13.4	2	0.2
18	8.5	8.3	5.0	13.0	7	0.3
19	8.7	8.3	7.3	12.3	1	0.2
20	8.7	8.1	10.6	12.0	2	0.2
21						
Max.	8.9		10.6	13.8	7	0.3
Min.		8.1	2.7	12.0	1	0.1
Avg			5.6	13.0	3	0.2
May '62						
22	8.7	8.1	22.1	8.4	3	0.5
23	8.3	7.9	22.9	8.3	3	0.7
24	9.5	8.1	21.7	7.9	2	0.5
25	8.2	8.1	19.3	8.7		
26	8.2	8.1	18.7	9.3		
27	8.2	8.1	18.3	8.8		
Max.	9.5		22.9	9.3	3	0.7
Min.		7.9	18.3	7.9	2	0.5
Avg			20.5	8.6	3	0.6

TABLE A7. SUMMARY OF DATA FROM STATION A5 ON STREAM A

Date	pH, max.	pH, min.	Avg temp, °C	Avg DO, mg/l	BOD, mg/l	Suspended solids, mg/l	Volatile suspended solids, mg/l	ABS, mg/l	NH_3, mg/l	NO_2, mg/l	NO_3, mg/l	PO_4, mg/l	Coliform per 100 ml
Aug '61													
16	8.0[a]		20.7	6.2	7	17	5	7.6	2.22	0.560	5.40	8	67,900
17	8.0		20.9	5.4	11	60	18	4.6	4.80	0.680	4.80	17	62,300
18	8.0		21.9	6.5	10	29	6	4.4	3.40	0.800	6.00	16	67,700
19	7.9		21.4	7.3	3	13	3	3.4	1.24	0.320	3.30	11	39,600
20	7.9		19.9	8.4	5	110	19	4.8	2.52	0.480	4.30	16	25,400
21	7.9		19.0	7.5	13	47	10	4.2	3.24	0.800	4.10	32	126,000
Max.	8.0		21.9	8.4	13	110	19	7.6	4.80	0.800	6.00	32	126,000
Min.	7.9		19.0	5.4	3	13	3	3.4	1.24	0.320	3.30	8	25,400
Avg			20.6	6.9	8	46	10	4.8	2.90	0.573	4.65	17	64,800
Mar '62													
15	8.3	8.0	5.0	12.3	2	14	14	1.1	0.20	0.036	1.11	6	13,900
16	8.2	8.1	4.0	12.4	2	10	9	1.3	0.10	0.028	1.68	6	15,100
17	8.3	7.5	5.0	12.1	2	5	5	1.4	0.13	0.030	2.88	7	9,100
18	8.2	7.9	5.8	12.1	4	8	8	1.5	0.10	0.024	2.92	7	7,700
19	8.2	8.0	8.0	11.3	2	25	17	1.5	0.13	0.032	3.28	7	13,400
20	8.3	7.9	10.6	11.1	4	72	17	1.2	0.10	0.026	2.32	4	17,500
21													
Max.	8.3		10.6	12.4	4	72	17	1.4	0.20	0.036	3.28	7	17,500
Min.		7.5	4.0	11.1	2	5	5	1.1	0.10	0.024	1.11	4	7,700
Avg			6.4	11.9	3	22	12	1.3	0.13	0.029	2.37	6	12,800
May '62													
22	8.5	7.6	20.6	8.0	4	100	10	2.4	0.28	0.056	1.30	17	45,300
23	8.2	6.6	21.6	7.4	2	39	19	2.1	0.08	0.007	1.10	14	4,500
24	8.3	8.0	20.1	8.3	3	18	7	1.7	0.08	0.004	0.97	11	2,700
25	8.1	8.0	18.8	8.9									
26	8.0	7.9	17.3	8.6									
27	8.0	7.8	17.2	8.8									
Max.	8.5		21.6	8.9	4	100	19	2.4	0.28	0.056	1.30	17	45,300
Min.		7.6	17.2	7.4	2	18	7	1.7	0.08	0.004	0.97	11	2,700
Avg			19.3	8.3	3	53	12	2.1	0.15	0.022	1.12	14	17,500

[a] pH on 24 hr composite for August

APPENDIX B

TABLE B1. SUMMARY OF RAW SEWAGE DATA AT SEWAGE TREATMENT PLANT B

Date	Flow, gpd	pH, max.	pH, min.	Avg temp, °C	BOD, mg/l	Total solids, mg/l	Total volatile solids, mg/l	Suspended solids, mg/l	Volatile suspended solids, mg/l	ABS, mg/l	Coliform per 100 ml
Aug. '61											
8	20,400		7.3[a]	25.5	340			190	150		50,600,000
9	18,400		7.3	24.9	330			470	380		72,200,000
10	18,000		7.4	24.8	360			180	140		57,400,000
11	18,900		7.7	24.4	320			260	310		34,900,000
12	22,800		7.5	24.8	300			610	190		23,900,000
13	26,600		7.4	23.9	280			160	160		51,100,000
14	21,200		7.5	24.8	310			200	140		78,900,000
Max.	26,600		7.7	25.5	360			610	380		78,900,000
Min.	18,000		7.3	23.9	280			160	140		23,900,000
Avg	20,900			24.7	320			300	210		52,700,000
Dec. '61											
12	27,800	7.9	7.3	15.1	220	710	320	130	120		27,300,000
13	23,900	8.1	7.4	14.5	240	780	310	340			33,300,000
14	24,000	8.1	7.4	14.7	250	880	360	520	360		23,600,000
15	22,300	8.3	7.4	15.1	310	920	400	220	180		41,400,000
16	47,300	8.2	7.2	14.8	230	670	350	350	340		21,800,000
17	36,200	7.6	7.3	14.7	170	610	290	140	140		13,900,000
18	42,800	7.7	7.1	15.2	260	1060	690	190	170		24,300,000
Max.	47,300	8.3		15.2	310	1060	690	520	360		41,400,000
Min.	22,300		7.1	14.5	170	610	290	130	120		13,900,000
Avg	32,000			14.9	240	800	390	270	220		26,500,000
Mar. '62											
6	32,000	8.0	6.9	11.7	380	750	380	140	120		15,000,000
7	39,900	8.0	6.1	11.2	200	710	320	170	150	15.9	27,700,000
8	59,100	8.3	7.0	11.3	310	590	270	170	140	9.6	45,900,000
9	71,500	7.8	7.0	10.7	140	460	180	67	49	5.7	17,400,000
10	46,800	8.2	7.8	10.8	280	620	260	83	70	9.3	22,400,000
11	58,100	8.2	7.5	11.5	170	520	220	120	110	5.5	9,700,000
12	45,300	8.2	7.3	11.3	270	620	290	100	94	11.2	12,300,000
Max.	71,500	8.3		11.7	380	750	380	170	150	15.9	45,900,000
Min.	32,000		6.1	10.7	140	460	180	67	49	5.5	9,700,000
Avg	50,400			11.2	250	610	280	120	110	9.5	21,500,000
May '62											
14	28,000	8.3	7.4	18.7	320	930	480	290	210	23.4	38,800,000
15	23,900	7.8	7.3	18.8	380	1100	530	390	280	28.2	51,100,000
16	21,300	7.9	7.6	18.7	330	950	470	280	210	25.8	29,700,000
17	22,000	8.0	7.3	19.1	290	920	390	210	170	32.2	22,800,000
18	22,400	8.1	7.7	19.0	280	940	390	210	170	26.6	55,400,000
19	23,600	8.2	6.9	20.2	300	980	400	250	180	31.6	25,300,000
20	22,300	8.0	7.7	19.3	280	850	390	180	120	19.0	31,300,000
Max.	28,000	8.3		20.2	380	1100	530	390	280	32.2	55,400,000
Min.	21,300		6.9	18.7	280	850	390	180	120	19.0	22,800,000
Avg	23,400			19.1	310	950	440	260	190	26.7	36,300,000

[a] pH on 24-hr composite for August

TABLE A9. SUMMARY OF DATA FROM STATION M2 ON STREAM M

Date	pH, max.	pH, min.	Avg temp, °C	Avg DO, mg/l	BOD, mg/l	ABS, mg/l
Aug. '61						
15		8.1[a]	23.5	8.5	3	2.1
Mar. '62						
15	8.8	8.0	3.8	13.3	2	0.4
16	8.6	8.3	3.0	13.6	1	0.4
17	8.6	8.3	4.4	12.9	2	0.5
18	8.6	8.3	5.0	12.9	2	0.5
19	8.8	8.3	7.5	12.1	3	0.5
20	8.8	8.1	10.7	11.9	3	0.5
21						
Max.	8.8		10.7	13.6	3	0.5
Min.		8.0	3.0	11.9	1	0.4
Avg			5.7	12.8	2	0.5
May '62						
22	8.4	8.0	22.6	8.1	3	1.4
23	8.4	8.1	22.7	7.9	3	1.2
24	8.4	8.1	21.6	8.2	3	1.1
25	8.3	8.2	19.5	8.9		
26	8.3	8.2	18.5	12.4		
27	8.3	8.1	18.0	8.7		
Max.	8.4		22.7	12.4	3	1.4
Min.		8.0	18.0	7.9	3	1.1
Avg			20.5	9.0	3	1.2

[a] pH on 24-hr composite for August

TABLE B2. SUMMARY OF MIXED LIQUOR DATA AT SEWAGE TREATMENT PLANT B

Date	pH, max.	pH, min.	Avg temp, °C	Avg DO, mg/l	Suspended solids, mg/l	Volatile suspended solids, mg/l	Settleability (30 min), ml/l
Aug. '61							
8		7.4[a]	25.6				440
9		7.4	25.2	1.0	6, 580	4, 120	900
10		7.4	25.5	0.6	5, 480	3, 530	470
11		7.4	25.8	1.9	6, 000	3, 890	360
12		7.3	25.0	2.7	5, 910	3, 990	630
13		7.3	24.4	2.5	6, 090	4, 150	510
14		7.4	24.8	2.3	6, 440	4, 140	510
Max.		7.4	25.8	2.7	6, 580	4, 150	900
Min.		7.3	24.4	0.6	5, 480	3, 530	360
Avg			25.2	1.8	6, 080	3, 970	546
Dec. '61							
12	7.4	7.1	14.0	3.1	6, 380	4, 380	485
13	7.2	7.1	12.3	4.2	6, 580	4, 800	480
14	7.2	6.9	11.7	3.7	7, 240	4, 320	530
15	7.9	7.1	11.8	4.0	6, 260	4, 380	590
16	7.1	6.8	12.2	3.9	6, 220	4, 260	470
17	8.0	7.0	13.3	3.0	6, 600	4, 680	530
18	7.2	6.9	14.0	1.8	6, 480	4, 520	430
Max.	8.0		14.0	4.2	7, 240	4, 800	590
Min.		6.8	11.7	1.8	6, 220	4, 260	430
Avg			12.8	3.4	6, 540	4, 480	502
Mar. '62							
6	8.2	6.6	9.8	2.1	4, 640	3, 440	360
7	7.3	6.0	10.2	2.3	4, 440	3, 040	355
8	7.5	7.0	10.5	1.5	5, 360	3, 760	400
9	7.5	7.2	10.0	2.4	5, 340	3, 520	395
10	8.0	7.3	10.2	2.6	5, 180	3, 500	408
11	8.4	7.3	11.2	1.7	5, 180	3, 560	415
12	7.4	7.1	10.8	1.6	5, 380	3, 840	403
Max.	8.4		11.2	2.6	5, 380	3, 840	415
Min.		6.0	9.8	1.5	4, 440	3, 040	355
Avg			10.4	2.0	5, 070	3, 520	391
May '62							
14	7.4	6.8	20.7	0.5	8, 000	5, 220	895
15	7.3	6.1	21.3	0.6	7, 860	5, 000	600
16	7.6	7.3	21.5	0.3	8, 320	5, 640	660
17	7.4	6.8	21.5	0.4	7, 980	5, 360	630
18	7.5	7.3	22.0	0.2	7, 900	5, 140	720
19	7.6	7.0	22.3	0.5	8, 220	5, 440	860
20	7.5	7.2	22.3	0.2	7, 960	5, 150	580
Max.	7.6		22.3	0.6	8, 320	5, 640	895
Min.		6.1	20.7	0.2	7, 860	5, 000	580
Avg			21.7	0.4	8, 030	5, 280	706

[a] pH on 24-hr composite for August

TABLE B4. SUMMARY OF DATA FROM STATION B4 ON STREAM B

Date	pH, max.	pH, min.	Avg temp, °C	Avg DO, mg/l	BOD, mg/l	Suspended solids, mg/l	Volatile suspended solids, mg/l	ABS, mg/l	NH_3, mg/l	NO_2, mg/l	NO_3, mg/l	PO_4, mg/l	Coliform per 100 ml
Aug. '61													
8		7.8[a]	25.7	4.4	8	14	6	1.5	0.64	0.144	22.40	62	
9		7.7	24.3	4.3	4	16	10	1.5	0.72	0.176	24.00	70	
10		7.7	24.6	4.3	6	31	6	0.8	0.68	0.164	26.00	50	
11		7.5	25.3	5.0	5	14	6	0.7	0.58	0.112	18.00	40	
12		7.6	24.8	5.5	4	5	5	0.9	0.68	0.160	24.00	102	
13		7.7	22.8	5.9	5	8	7	0.6	0.54	0.184	24.00	66	
14		8.0	24.0	5.6	3	8	7		0.58	0.236	26.00	60	
Max.		8.0	25.7	5.9	8	31	10	1.5	0.72	0.236	26.00	102	
Min.		7.5	22.8	4.3	3	5	5	0.6	0.54	0.112	18.00	50	
Avg			24.5	5.0	5	14	7	1.0	0.63	0.168	23.50	64	
Dec. '61													
12	7.8	7.4	6.8	9.9	6	16	11		0.48	0.028	2.40	5	
13	8.1	7.4	1.7	11.7	6	14	12		0.42	0.026	3.50	10	
14	7.7	7.4	1.6	11.5	4	70	14		0.48	0.033	5.60	16	
15	8.4	7.4	1.8	11.7	5	18	14		0.48	0.038	6.20	21	
16	7.7	7.3	3.2	11.2	10	100	26		0.70	0.400	5.80	19	
17	7.5	7.4	5.8	11.3	6	36	19		0.48	0.021	2.30	2	
18	7.5	7.4	5.4	11.4	11	38	17		0.44	0.020	2.00	2	
Max.	8.4		6.8	11.7	11	100	26		0.70	0.400	6.20	21	
Min.		7.3	1.6	9.9	4	14	11		0.42	0.020	2.00	2	
Avg			3.8	11.2	7	42	16		0.50	0.081	4.00	11	
Mar. '62													
6	8.0	6.8	1.7	12.2	7	12	12	0.6	0.42	0.020	0.60	4	60, 600
7	8.1	7.4	3.1	12.1	18	47	34	5.1	0.44	0.041	1.70	5	128, 000
8	9.5	7.6	4.9	12.0	5	83	21	0.4	0.34	0.018	1.60	3	37, 200
9	8.0	7.6	4.1	11.5	8	73	9	0.1	0.30	0.010	1.20	1	168, 000
10	8.2	7.6	5.4	11.2	6	23	6	0.3	0.28	0.020	2.20	2	124, 000
11	8.2	8.0	7.1	10.6	3	62	16	0.3	0.26	0.026	1.40	2	71, 800
12	7.7	6.2	7.0	10.8	3	27	11	0.3	0.40	0.023	1.30	2	55, 400
Max.	9.5		7.1	12.2	18	83	34	5.1	0.44	0.041	2.20	5	168, 000
Min.		6.2	1.7	10.6	3	12	6	0.1	0.26	0.010	0.60	1	37, 200
Avg			4.8	11.5	7	47	16	1.0	0.35	0.023	1.40	3	92, 100
May '62													
14	8.0	7.7	24.7	9.8	8	12	4	3.9	5.68	0.280	0.40	30	94, 000
15	8.0	7.6	24.9	8.6	9	19	1	5.3	3.84	0.363	0.23	37	76, 000
16	8.1	7.6	24.7	8.6	9	20	12	6.5	4.56	0.500	0.45	43	112, 000
17	8.1	7.0	24.2	5.9	8	30	13	5.8	3.56	0.380	0.30	46	125, 000
18	8.1	7.6	25.6	8.3	8	26	8	6.2	2.14	0.371	0.50	42	91, 000
19	8.0	7.0	25.7	7.5	6	21	11	5.8	1.70	0.213	0.35	36	145, 000
20	8.1	7.6	25.0	7.2	8	19	8	6.2	1.84	0.255	0.30	38	71, 000
Max.	8.1		25.7	9.8	9	30	13	6.5	5.68	0.500	0.50	46	145, 000
Min.		7.0	24.2	5.9	6	12	1	3.9	1.70	0.213	0.23	30	71, 000
Avg			25.0	8.0	8	21	8	5.7	3.33	0.337	0.36	39	102, 000

[a] pH on 24-hr composite for August

TABLE B3. SUMMARY OF PLANT EFFLUENT DATA AT SEWAGE TREATMENT PLANT B

Date	pH, max.	pH, min.	Avg temp, C	Avg DO, mg/l	BOD, mg/l	Total solids, mg/l	Total volatile solids, mg/l	Suspended solids, mg/l	Volatile suspended solids, mg/l	Settleable solids, mg/l	ABS, mg/l	NH_3, mg/l	NO_2, mg/l	NO_3, mg/l	PO_4, mg/l	Coliform per 100 ml
Aug. '61																
8		7.5[a]	25.5	1.8	10				13	< 0.1	1.8	0.48	0.070	8.2	70	557,000
9	7.5		24.8	1.8	9			17	7	< 0.1	1.5	0.46	0.130	30.0	52	1,080,000
10	7.5		25.5	1.6	9			30	11	< 0.1	0.9	0.42	0.204	36.0	68	1,490,000
11	7.4		25.3	1.5	10			20	14	< 0.1	0.9	0.48	0.196	28.0	62	837,000
12	7.5		24.6	1.8	6			12	12	< 0.1	1.0	0.62	0.236	32.0	116	596,000
13	7.5		24.3	1.5	8			12	12	< 0.1	0.9	0.44	0.196	30.0	66	555,000
14	7.7		24.5	1.4	11			14	9	< 0.1		0.44	0.304	28.0	64	464,000
Max.	7.7		25.5	1.5	11			30	14		1.8	0.62	0.304	36.0	116	1,490,000
Min.	7.4		24.3	1.4	6			12	7		0.9	0.42	0.070	8.4	52	464,000
Avg			25.0	1.6	9			18	11	< 0.1	1.2	0.48	0.192	27.5	71	797,000
Dec. '61																
12	7.3	7.0	12.9	0.9	14	590	21^0	14	12	< 0.1		0.54	0.170	17.2	70	108,000
13	7.3	7.1	10.9	1.2	10	520	18^0	15	12	< 0.1		0.42	0.120	18.8	64	77,400
14	7.2	7.0	11.3	1.3	8	630	19^0	69	13	< 0.1		0.54	0.140	21.6	68	64,800
15	8.0	6.9	11.3	1.1	8	640	18^0	20	7	< 0.1		0.48	0.140	25.6	74	100,000
16	7.1	6.8	11.8	1.3	> 71	1920	110^0	1500	1200	2.5		3.00	0.520	23.2	174	2,070,000
17	7.5	6.8	13.0	0.8	24	540	18^0	20	18	0.2		1.06	0.600	17.6	48	317,000
18	7.5	7.0	13.6	0.5	34	720	32^0	190	150	1.3		0.54	0.320	17.6	63	353,000
Max.	8.0		13.6	1.3	> 71	1920	110^0	1500	1200	2.5		3.00	0.600	25.6	174	2,070,000
Min.		6.8	10.9	0.5	8	540	18^0	14	7	< 0.1		0.42	0.120	17.2	48	64,800
Avg			12.1	1.0	16	800	34^0	260	200			0.94	0.287	20.2	80	441,000
Mar. '62																
6	7.4	6.9	9.4	2.1	21	580	21^0	29	29	< 0.1	4.6	1.06	0.106	17.6	40	294,000
7	7.5	6.8	10.1	1.0	100	730	32^0	180	160	6.3	15.8	2.72	0.465	14.8	48	396,000
8	7.6	6.0	10.1	0.5	34	520	19^0	45	43	0.5	5.2	1.30	0.140	20.8	38	523,000
9	7.4	6.9	10.1	1.2	210	1000	50^0	490	350	38.0	3.5	1.74	0.315	16.0	60	9,820,000
10	7.5	6.8	10.2	0.8	34	470	16^0	32	20	0.1	4.0	2.04	0.180	19.4	24	2,390,000
11	7.5	7.0	11.3	0.7	43	550	21^0	110	88	1.8	3.4	1.16	0.270	16.4	26	1,970,000
12	7.6	6.9	10.9	0.4	50	520	28^0	58	52	< 0.1	4.2	2.48	0.380	17.6	30	1,700,000
Max.	7.6		11.3	2.1	210	1000	50^0	490	350	38.0	15.8	2.72	0.465	20.8	60	9,820,000
Min.		6.0	9.4	0.4	21	470	16^0	29	20	< 0.1	3.4	1.06	0.106	14.8	24	294,000
Avg			10.3	1.0	70	620	27^0	130	110		5.8	1.79	0.265	17.5	38	2,442,000
May '62																
14	7.5	7.1	20.5	0.2	26	670	8^5	15	13	< 0.1	6.4	7.06	0.009	0.25	58	1,440,000
15	7.5	6.9	21.3	0.5	27	660	15^0	12	8	< 0.1	7.1	6.70	0.012	0.10	62	3,300,000
16	7.8	7.2	21.6	0.3	28	640	16^0	16	16	< 0.1	7.4	5.96	0.008	0.20	62	2,030,000
17	7.5	7.0	21.8	0.2	34	660	17^0	25	24	< 0.1	7.6	6.00	0.008	0.15	62	6,250,000
18	7.7	7.2	22.2	0.2	27	660	15^0	21	20	< 0.1	6.8	3.20	0.006	0.25	60	5,640,000
19	7.6	7.2	22.8	0.5	18	660	11^0	14	11	< 0.1	7.4	2.50	0.007	0.15	62	3,930,000
20	7.6	7.2	22.9	0.3	19	670	16^0	12	9	< 0.1	7.6	2.70	0.007	0.13	58	1,860,000
Max.	7.8		22.9	0.5	34	670	17^0	25	24		7.6	7.06	0.012	0.25	62	6,250,000
Min.		6.9	20.6	0.2	18	640	8^5	12	8		6.4	2.50	0.006	0.10	58	1,440,000
Avg			21.9	0.3	26	660	14^0	17	14	< 0.1	7.2	4.87	0.008	0.18	61	3,850,000

[a] pH on 24 hr composite for August

TABLE B6. SUMMARY OF DATA FROM STATIONS B5a AND B6 ON STREAM B

Date	pH, max.	pH, min.	Avg temp, °C	Avg Do, mg/l	BOD, mg/l	Suspended solids, mg/l	Volatile suspended solids, mg/l	ABS, mg/l	NH_3, mg/l	NO_2, mg/l	NO_3, mg/l	PO_4, mg/l
Station B6 on Stream B												
Aug. '61												
8		8.2[a]	25.8	9.1	4	16	4	1.2	0.46	0.144	0.84	4
9		8.2	25.0	10.7	4	7	3	1.3	0.30	0.156	0.24	8
10		8.1	24.3	7.6	8	120	25	0.8	0.40	0.168	0.48	6
11		7.9	24.3	6.2	7	72	20	0.8	0.36	0.200	2.40	12
12		8.1	24.8	9.7	5	27	12	0.9	0.40	0.188	2.88	12
13		8.2	22.9	11.1	5	17	11	0.9	0.30	0.248	2.80	11
14		8.4	24.6	11.8	6	24	8		0.30	0.232	0.88	6
Max.		8.4	25.8	11.8	8	120	25	1.3	0.46	0.248	2.88	12
Min.		7.9	22.9	6.2	4	7	3	0.8	0.30	0.144	0.24	4
Avg			24.5	9.5	6	40	12	1.0	0.37	0.191	1.47	9
Station B5a on Stream B												
Dec. '61												
12	7.7	7.5	6.8	9.8	5	15	11		0.58	0.035	2.70	4
13	8.2	7.4	0.6	12.6	4	10	9		0.54	0.023	2.60	5
14	7.8	7.4	0.6	11.4	4	53	7		0.78	0.032	3.80	11
15	8.4	7.4	1.4	11.6	4	14	10		0.70	0.026	4.30	11
16	7.9	7.5	1.2	12.2	4	210	34		0.86	0.039	4.30	12
17	7.6	7.5	5.6	11.3	4	81	21		0.52	0.024	3.00	2
18	7.8	7.6	5.2	11.4	6	98	18		0.42	0.022	2.60	2
Max.	8.4		6.8	12.6	6	210	34		0.86	0.039	4.30	12
Min.		7.4	0.6	9.8	4	10	7		0.42	0.022	2.60	2
Avg			3.1	11.5	4	68	16		0.63	0.029	3.30	7
Mar. '62												
6	8.4	6.4	0.6	12.6	3	25	18	0.5	0.58	0.020	1.15	3
7	8.3	7.0	2.6	12.7	3	41	15	0.5	0.50	0.021	1.16	3
8	8.5	7.1	4.3	12.7	2	200	36	0.2	0.33	0.016	1.26	2
9	8.0	7.0	3.7	12.1	3	210	18	0.1	0.30	0.012	0.44	2
10	8.2	7.6	5.0	11.4	2	37	6	0.3	0.32	0.018	1.16	1
11	8.3	7.7	6.4	11.4	2	71	8	0.3	0.28	0.017	1.38	1
12	7.9	7.2	6.6	10.9	2	51	10	0.2	0.50	0.019	1.02	1
Max.	8.5		6.6	12.7	3	210	36	0.5	0.58	0.021	1.38	3
Min.		6.4	0.6	10.9	2	25	6	0.1	0.28	0.012	0.44	1
Avg			4.2	12.0	2	91	16	0.3	0.40	0.017	1.08	2
May '62												
14	8.4	7.7	23.8	8.1	13	22	14	1.8	1.04	0.200	1.00	9
15	8.4	7.7	23.9	8.2	6	19	2	2.3	1.13	0.202	0.80	10
16	8.5	7.8	23.6	7.8	5	13	8	2.4	1.16	0.270	0.50	8
17	8.3	7.1	23.2	5.3	5	15	10	2.9	1.47	0.310	0.90	14
18	8.4	7.8	24.6	8.0	4	13	5	3.4	1.65	0.300	0.98	18
19	8.4	7.9	25.0	8.5	4	13	5	2.7	1.04	0.371	1.15	10
20	8.5	7.7	24.1	8.0	5	39	5	3.3	1.04	0.352	1.03	9
Max.	8.5		25.0	8.5	13	39	14	3.4	1.65	0.371	1.15	18
Min.		7.1	23.2	5.3	4	13	2	1.8	1.04	0.200	0.50	8
Avg			24.0	7.7	6	19	7	2.7	1.22	0.286	0.91	11

[a] pH on 24-hr composite for August

TABLE B5. SUMMARY OF DATA FROM STATION B5 ON STREAM B

Date	pH, max.	pH, min.	Avg temp, °C	Avg DO, mg/l	BOD, mg/l	Suspended solids, mg/l	Volatile suspended solids, mg/l	ABS, mg/l	NH_3, mg/l	NO_2, mg/l	NO_3, mg/l	PO_4, mg/l	Coliform per 100 ml
Aug. '61													
8		8.0[a]	21.8	7.2	6	13	4	1.1	0.40	0.050	27.20	14	45, 700
9		7.9	21.8	5.9	4	63	44	1.1	0.22	0.024	8.50	31	178, 000
10		7.9	21.7	6.0	4	40	9	0.7	0.22	0.072	7.50	10	72, 700
11		7.8	21.9	6.1	6	60	16	0.7	0.40	0.144	5.50	15	121, 000
12		7.8	22.6	7.8	5	24	10	0.7	0.32	0.080	7.50	16	32, 800
13		7.9	20.2	7.9	4	19	8	0.6	0.24	0.064	6.25	18	14, 300
14		8.1	20.6	7.1	5	15	5		0.26	0.152	4.50	11	40, 800
Max.		8.1	22.6	7.9	6	63	44	1.1	0.40	0.152	27.20	31	178, 000
Min.		7.8	20.2	5.9	4	13	4	0.6	0.22	0.024	4.50	10	14, 300
Avg			21.5	6.9	5	33	14	0.8	0.29	0.084	9.56	16	72, 200
Dec. '61													
12	7.8	7.6	6.5	10.4	6	13	12		0.52	0.033	2.30	5	42, 900
13	8.4	7.6	0.5	13.0	4	21	13		0.54	0.025	3.20	8	13, 700
14	8.0	7.5	0.0	12.8	4	53	17		0.44	0.026	3.40	10	3, 200
15	8.4	7.7	0.6	14.0	4	12	10		0.54	0.032	4.30	11	6, 200
16	8.0	7.3	0.8	13.3	3	36	22		0.59	0.033	4.50	14	15, 100
17	7.7	7.5	6.0	11.9	4	46	19		0.54	0.024	2.20	2	68, 400
18	7.7	7.6	5.0	11.7	8	56	22		0.48	0.023	2.00	3	41, 600
Max.	8.4		6.5	14.0	9	56	22		0.59	0.033	4.50	14	68, 400
Min.		7.3	0.0	10.4	3	12	10		0.44	0.023	2.00	2	3, 200
Avg			2.8	12.4	5	34	16		0.52	0.028	3.10	8	27, 300
Mar. '62													
6	8.5	7.4	0.9	13.1	4	10	9	0.4	0.65	0.016	1.12	3	11, 100
7	8.7	7.7	2.9	12.8	5	25	17	0.5	0.36	0.036	1.12	3	94, 100
8	8.1	7.6	4.2	12.5	4	82	28	0.3	0.34	0.016	1.04	2	28, 600
9	8.1	7.3	4.1	12.3	4	92	12	0.2	0.31	0.010	0.72	1	250, 000
10	8.4	7.8	5.1	11.8	3	39	6	0.2	0.34	0.019	1.08	1	98, 100
11	8.4	7.6	6.2	11.5	3	54	6	0.3	0.44	0.019	1.32	2	94, 000
12	8.0	7.6	6.9	11.2	3	36	14	0.2	0.26	0.020	0.84	1	97, 400
Max.	8.5		6.9	13.1	5	92	28	0.5	0.65	0.036	1.32	3	250, 000
Min.		7.3	0.9	11.2	3	10	6	0.2	0.26	0.010	0.72	1	11, 100
Avg			4.4	12.2	4	48	13	0.3	0.39	0.019	1.03	2	96, 200
May '62													
14	8.1	7.6	25.6	4.8	5	18	6	1.7	0.37	0.052	0.65	8	4, 100
15	7.9	7.6	20.9	4.1	6	23	3	2.8	1.60	0.100	0.20	15	9, 400
16	8.1	7.1	20.9	3.2	4	18	7	2.5	0.44	0.061	0.90	8	3, 400
17	8.3	7.0	21.1	3.3	3	19	9	2.7	0.49	0.090	0.50	8	4, 800
18	8.0	7.7	21.0	3.5	3	15	6	2.7	0.49	0.111	0.70	8	4, 700
19	8.3	7.1	21.4	3.1	3	20	6	3.6	0.49	0.066	0.40	13	5, 700
20	8.1	7.6	20.9	3.0	6	51	12	3.1	0.48	0.121	0.50	8	24, 000
Max.	8.3		25.6	4.8	6	51	12	3.6	1.60	0.121	0.90	15	24, 000
Min.		7.0	20.9	3.0	3	15	3	1.7	0.37	0.052	0.20	8	3, 400
Avg			21.7	3.8	4	25	7	2.7	0.62	0.086	0.55	10	9, 000

[a] pH on 24-hr composite for August

APPENDIX C

Benthic Organisms and Fish in Stream A

	Common Group Name	Family or Major Group
1.	Sludgeworm	Oligochaeta
2.	Leech	Hirudinea
3.	Aquatic Sow Bug	Isopoda
4.	Pulmonate Snail	Physidae
5.	Pulmonate Snail	Lymnaeidae
6.	Scud	Gammaridae
7.	Crayfish	Astacidae
8.	Fish	Cyprinidae
9.	Fish	Percidae
10.	Fish	Centrarchidae
11.	True Fly	Culicidae
12.	True Fly	Tendipedidae
13.	True Fly	Heleidae
14.	True Fly	Psychodidae
15.	True Fly	Tipulidae
16.	True Fly	Tabanidae
17.	True Fly	Anthomyiidae
18.	True Fly	Simulidae
19.	True Fly	Stratiomyiidae
20.	True Fly	Rhagionidae
21.	Beetle	Hydrophilidae
22.	Beetle	Dytiscidae
23.	Beetle	Psephenidae
24.	Beetle	Elmidae
25.	Beetle	Dryopidae
26.	Beetle	Haliplidae
27.	Mayfly	Beetibae
28.	Mayfly	Heptageniidae
29.	Caddisfly	Psychomyiidae
30.	Caddisfly	Hydropsychidae
31.	Caddisfly	Leptoceridae
32.	Alderfly	Sialidae
33.	Stonefly	Nemouridae
34.	Stonefly	Perlidae

APPENDIX D

Benthic Organisms and Fish in Stream B

	Common Group Name	Family or Major Group
1.	Sludgeworm	Oligochaeta
2.	Leech	Hirudinea
3.	Aquatic Sow Bug	Isopoda
4.	Pulmonate Snail	Physidae
5.	Pulmonate Snail	Lymnaeidae
6.	Orb Snail	Planorbidae
7.	Scud	Gammaridae
8.	Crayfish	Astacidae
9.	Fish	Cyprinidae
10.	Fish	Percidae
11.	Fish	Centrarchidae
12.	True Fly	Tendipedidae
13.	True Fly	Tabanidae
14.	True Fly	Tipulidae
15.	True Fly	Syrphidae
16.	True Bug	Nupidae
17.	True Bug	Belostomatidae
18.	Beetle	Halipidae
19.	Beetle	Psephenidae
20.	Beetle	Dryopidae
21.	Beetle	Dytiscidae
22.	Beetle	Hydrophilidae
23.	Mayfly	Baetidae
24.	Mayfly	Heptageniidae
25.	Caddisfly	Hydropsychidae
26.	Caddisfly	Psychomiidae
27.	Caddisfly	Limnephilidae
28.	Alderfly	Sialidae
29.	Stonefly	Perlidae
30.	Stonefly	Nemouridae

APPENDIX E

Summary of Data from an Extended-Aeration Plant Effluent Pond near Cincinnati[a]

Detention time, days	Pond influent		Pond effluent					D O, mg/l	
	BOD, mg/l	SS, mg/l	BOD, mg/l	SS, mg/l	VSS, mg/l	Temp, °C	Algal count, per ml. (5 PM)	max.	min.
5 [b]	25	125	18	54	37	20	240,000	41.6	0
3 [c]	9	12	7	13	9	12	44,000	11.5	5.5
1 [d]	6	11	5	11	9	13	10,000	6.7	5.3

[a] BOD, suspended solids, and volatile suspended solids values represent the averages of the 24-hour composite samples (except one 12-hour composite collected during the study of a 1-day detention time) collected during the periods shown below. The temperature shown is the average of hourly readings taken over the 24-hour sampling periods. DO samples were taken hourly.

[b] 5-day-detention-time data gathered from Sept. 5 to Oct. 12, 1962.

[c] 3-day-detention-time data gathered from Oct. 12 to Nov. 2, 1962.

[d] 1-day-detention-time data gathered from Nov. 2 to Nov. 16, 1962.